US009130704B2

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Zhang et al.

(10) **Patent No.: US 9,130,704 B2**
(45) **Date of Patent: *Sep. 8, 2015**

(54) **MULTI-CLOCK PHYSICAL LAYER [[PHY] PREAMBLE DESIGN AND DETECTION**

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(73) Assignee: **Marvell World Trade Ltd.**, St. Michael (BB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/193,428**

(22) Filed: **Feb. 28, 2014**

(65) **Prior Publication Data**

US 2014/0177743 A1 Jun. 26, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/365,963, filed on Feb. 3, 2012, now Pat. No. 8,665,974.

(60) Provisional application No. 61/441,610, filed on Feb. 10, 2011.

(51) **Int. Cl.**

H04K 1/10	(2006.01)
H04L 7/00	(2006.01)
H04L 27/26	(2006.01)

(52) **U.S. Cl.**

CPC ***H04L 7/0016*** (2013.01); ***H04L 27/2601*** (2013.01); ***H04L 27/2613*** (2013.01)

(58) **Field of Classification Search**

USPC 375/260; 370/349, 331, 208, 445

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,638,378	A *	6/1997	Scop et al.	370/445
7,274,652	B1	9/2007	Webster et al.	
7,349,462	B2	3/2008	Schott et al.	
7,577,117	B2	8/2009	Cho et al.	

(Continued)

OTHER PUBLICATIONS

IEEE Std 802.11b-2001 (Corrigendum to IEEE Std 802.11b-1999) "IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Amendment 2: Higher-speed Physical Layer (PHY) extension in the 2.4 GHz band-Corrigendum 1," *The Institute of Electrical and Electronics Engineers, Inc.*, Nov. 7, 2001.

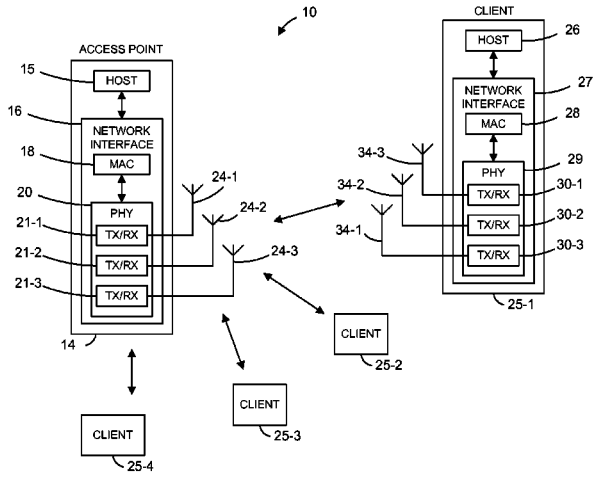
(Continued)

Primary Examiner — Eva Puente

(57) **ABSTRACT**

In a method for detecting, at a first communication device, a clock rate of a physical layer (PHY) data unit, the PHY data unit is received, at the first communication device, from a second communication device via a communication channel. The PHY data unit includes (i) a first portion and (ii) a second portion following the first portion. At the first communication device, the first portion of the PHY data unit is processed. Processing the first portion of the PHY data unit includes performing one or more autocorrelations to generate one or more respective autocorrelation outputs. At the first communication device and based on at least one of the one or more autocorrelation outputs, a clock rate of the second portion of the PHY data unit is determined.

21 Claims, 23 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

8,155,138	B2	4/2012	van Nee	
8,175,118	B2	5/2012	Zhang et al.	
8,175,119	B2	5/2012	Zhang et al.	
8,331,419	B2	12/2012	Zhang et al.	
8,385,440	B2	2/2013	Zhang et al.	
8,467,410	B2	6/2013	Morioka et al.	
8,526,351	B2	9/2013	Fischer et al.	
8,644,128	B2	2/2014	Zhang et al.	
8,655,974	B2	2/2014	Frey et al.	
8,724,720	B2	5/2014	Srinivasa et al.	
8,867,653	B2	10/2014	Zhang et al.	
2007/0086423	A1*	4/2007	Zeng et al.	370/349
2009/0196163	A1	8/2009	Du	
2010/0046542	A1	2/2010	van Zelst et al.	
2010/0157965	A1*	6/2010	Zeng et al.	370/338
2011/0002219	A1	1/2011	Kim et al.	
2012/0201316	A1	8/2012	Zhang et al.	
2012/0294294	A1	11/2012	Zhang	

OTHER PUBLICATIONS

Gunnam, et al., "Multi-Rate Layered Decoder Architecture for Block LDPC Codes of the IEEE 802.11n Wireless Standard," IEEE International Symposium on Circuits and Systems, 2007 (ISCAS 2007), pp. 1645-1648 (2007).

IEEE Std 802.11a-1999 (Supplement to IEEE Std 802.11-1999) "Supplement to IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-Speed Physical Layer in the 5 GHZ Band," *The Institute of Electrical and Electronics Engineers, Inc.*, (1999).

IEEE Std 802.11g/D8.2, Apr. 2003 (Supplement to ANSI/IEEE Std 802.11, 1999 (Reaff 2003)) "Draft Supplement to Standard [for] Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Further Higher Data Rate Extension in the 2.4 GHz Band," *The Institute of Electrical and Electronics Engineers, Inc.*, Apr. 2003.

Stacey et al., "IEEE P802.11, Wireless LANs, Proposed TGac Draft Amendment," Institute of Electrical and Electronics Engineers, doc. No. IEEE 802.11-10/1361r3 (Jan. 2011).

S. A. Mujtaba, "IEEE P802.11—Wireless LANs, TGn Sync Proposal Technical Specification," *The Institute of Electrical and Electronics Engineers, Inc.*, doc.: IEEE 802.11-04/0889r6, May 2005.

"IEEE P802.11 nTM/D3.00, Draft Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: Enhancements for Higher Throughput," *The Institute of Electrical and Electronics Engineers, Inc.*, Sep. 2007.

"IEEE Std. 802.11nTM IEEE Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment 5: Enhancements for Higher Throughput," *The Institute of Electrical and Electronics Engineers, Inc.*, Oct. 2009.

U.S. Appl. No. 13/365,950, filed Feb. 3, 2012.

PCT Application No. PCT/US12/23807 filed Feb. 3, 2012.

International Search report and Written Opinion for International Application No. PCT/US2012/023807, dated Jun. 18, 2012.

Yu, et al. "Coverage extetion for IEEE802.11ah," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/0035r1, (Jan. 2011).

International Preliminary Report on Patentability in corresponding PCT/US2012/023807 mailed Aug. 22, 2013.

IEEE Std 802.11ac/D2.0 "Draft Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz," *The Institute of Electrical and Electronics Engineers, Inc.*, pp. 1-359 (Jan. 2012).

IEEE Std 802.11af/D1.05 "Draft Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: TV White Spaces Operation," *The Institute of Electrical and Electronics Engineers, Inc.*, pp. 1-123 (Nov. 2011).

de Vegt, "Potential Compromise for 802.11ah Use Case Document", Institute of Electrical and Electronics Engineers, doc. No. IEEE 802.11-11/0457r0, pp. 1-27 (Mar. 2011).

Park, "Proposed Specification Framework for TGah", *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11--yy/xxxxr05, (Jan. 2012).

Perahia, et al., "Gigabit Wireless LANs: an overview of IEEE 802.11ac and 80211ad," ACM SIGMOBILE Mobile Computing and Communications Review, vol. 15, No. 3, pp. 23-33 (Jul. 2011.

Stacey et al., "Specification Framework for TGac," document No. IEEE 802.11-09/0992r20, *Institute for Electrical and Electronics Engineers*, pp. 1-49, (Jan. 18, 2011).

Taghavi et al., "Introductory Submission for TGah", doc. No. IEEE 802.11-11/0062r0, *Institute for Electrical and Electronics Engineers*, pp. 1-5 (Jan. 14, 2011).

Vermani, et al. "Preamble Format for 1 MHz," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/1482r2, pp. 1-30 (Nov. 2011).

Vermani, et al. "Spec Framework Text for PHY Numerology," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/13111-0, pp. 1-5 (Sep. 2011).

Zhang et al., "11ah Data Transmission Flow," *The Institute of Electrical and Electronics Engineers*, doc. No. IEEE 802.11-11/1484r1, pp. 1-15 (Nov. 2011).

* cited by examiner

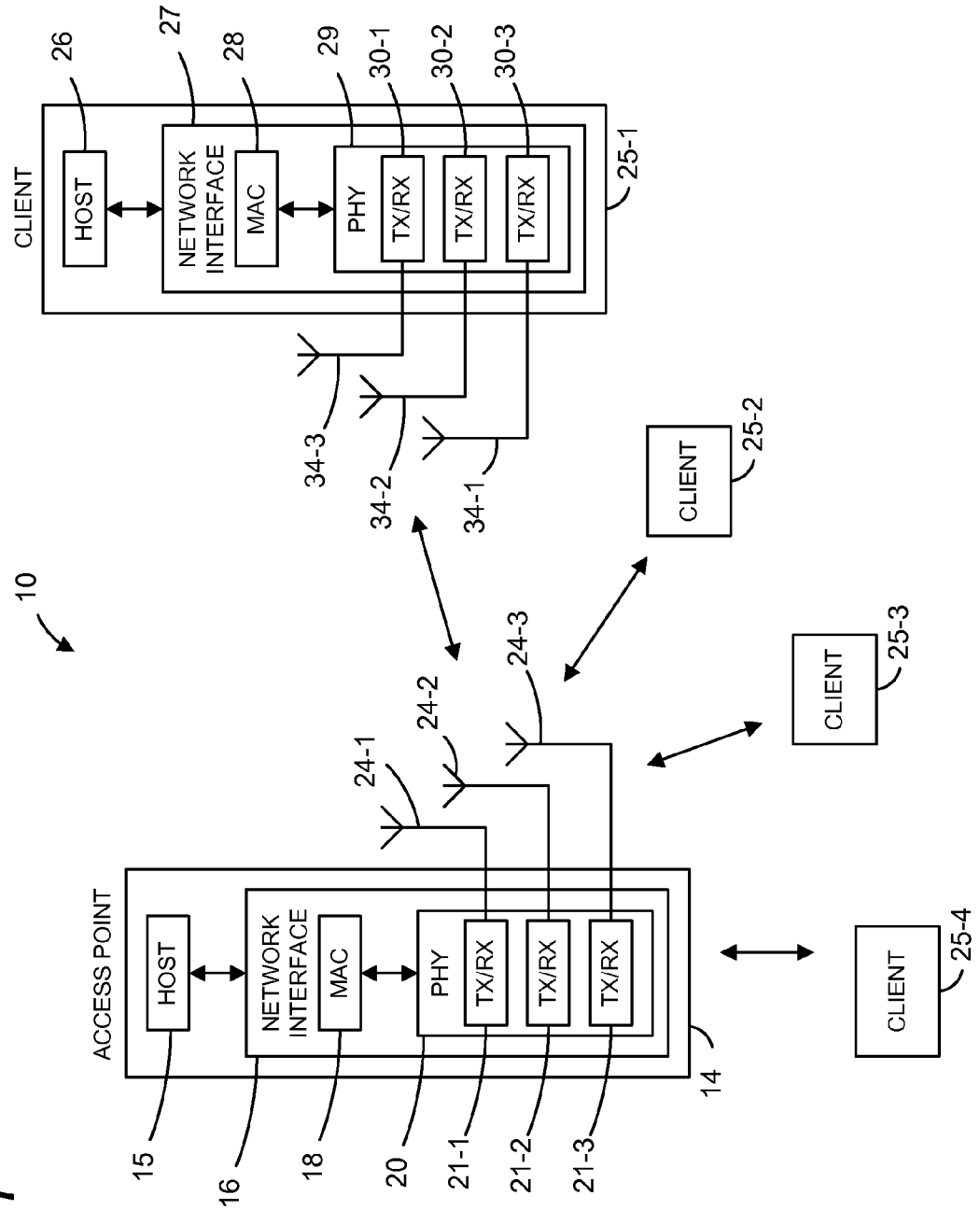

10
ACCESS POINT
HOST
NETWORK INTERFACE
MAC
PHY
TX/RX
TX/RX
TX/RX
14
15
16
18
20
21-1
21-2
21-3
24-1
24-2
24-3
CLIENT
25-1
25-2
25-3
25-4
26
27
28
29
30-1
30-2
30-3
34-1
34-2
34-3

FIG. 1

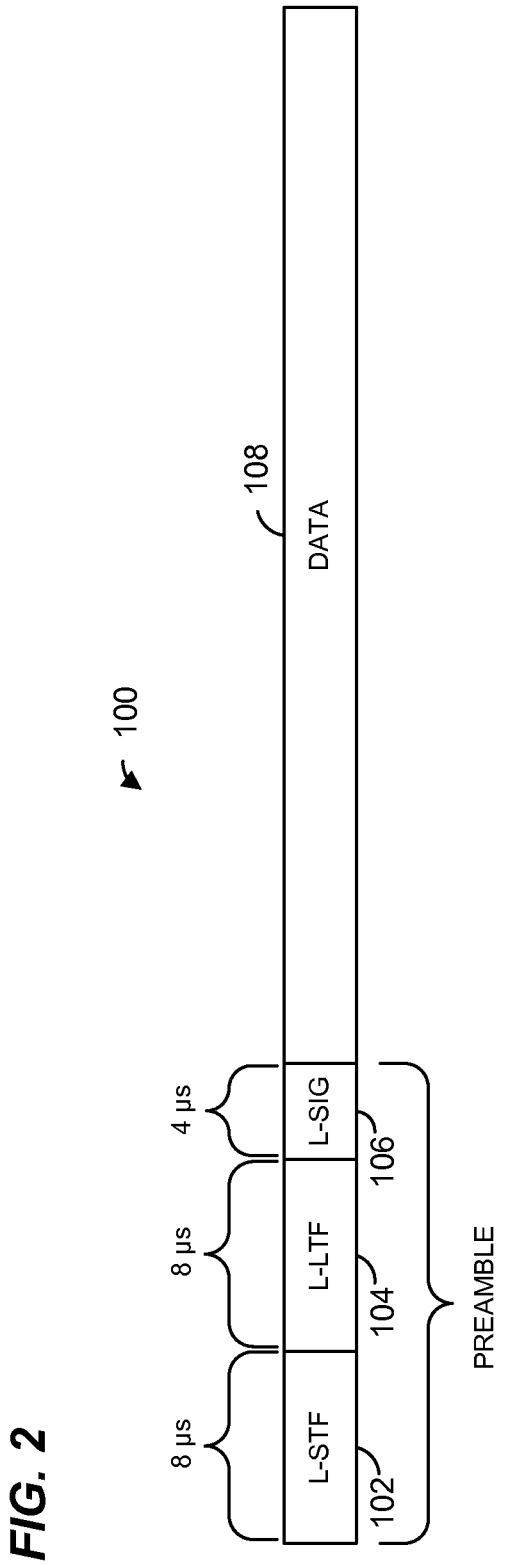
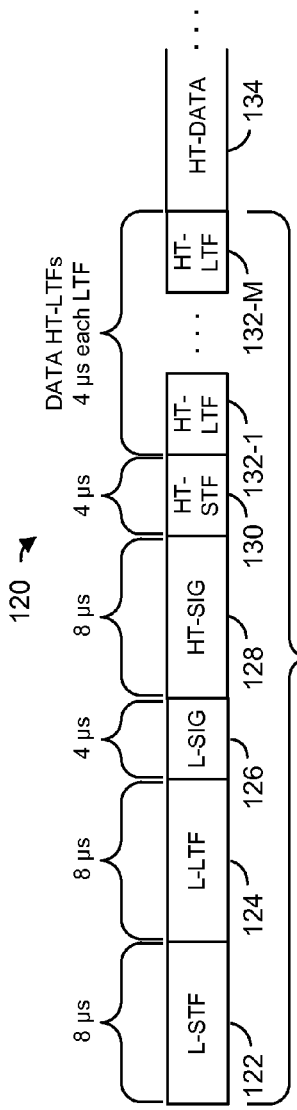


FIG. 2

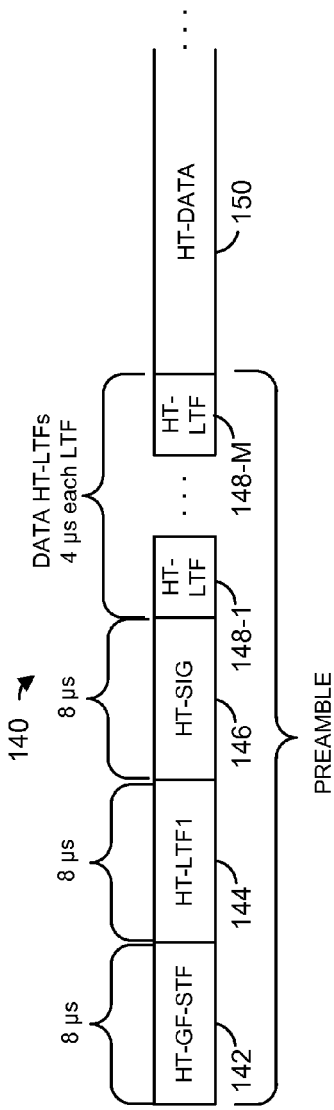
PRIOR ART

FIG. 3



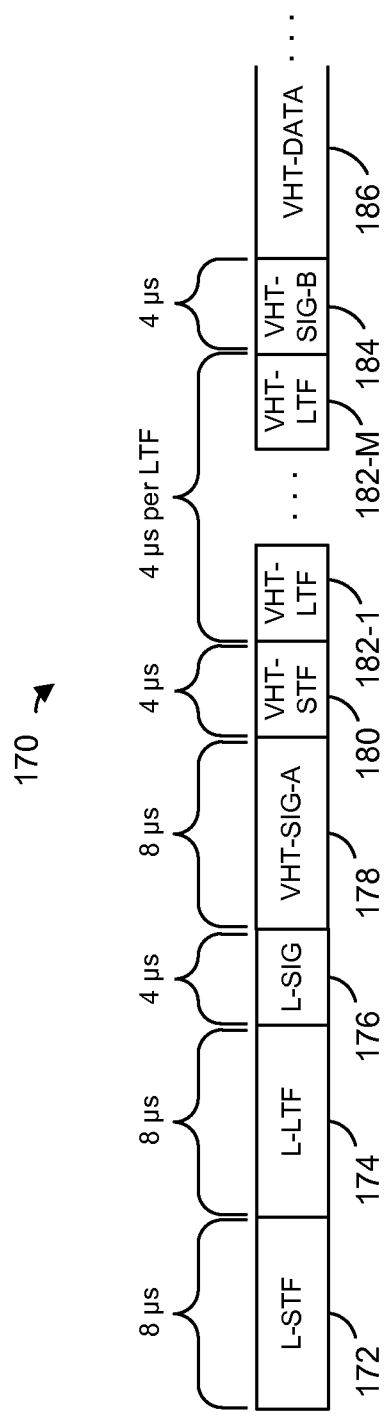
PRIOR ART

FIG. 4



PRIOR ART

FIG. 5



PRIOR ART

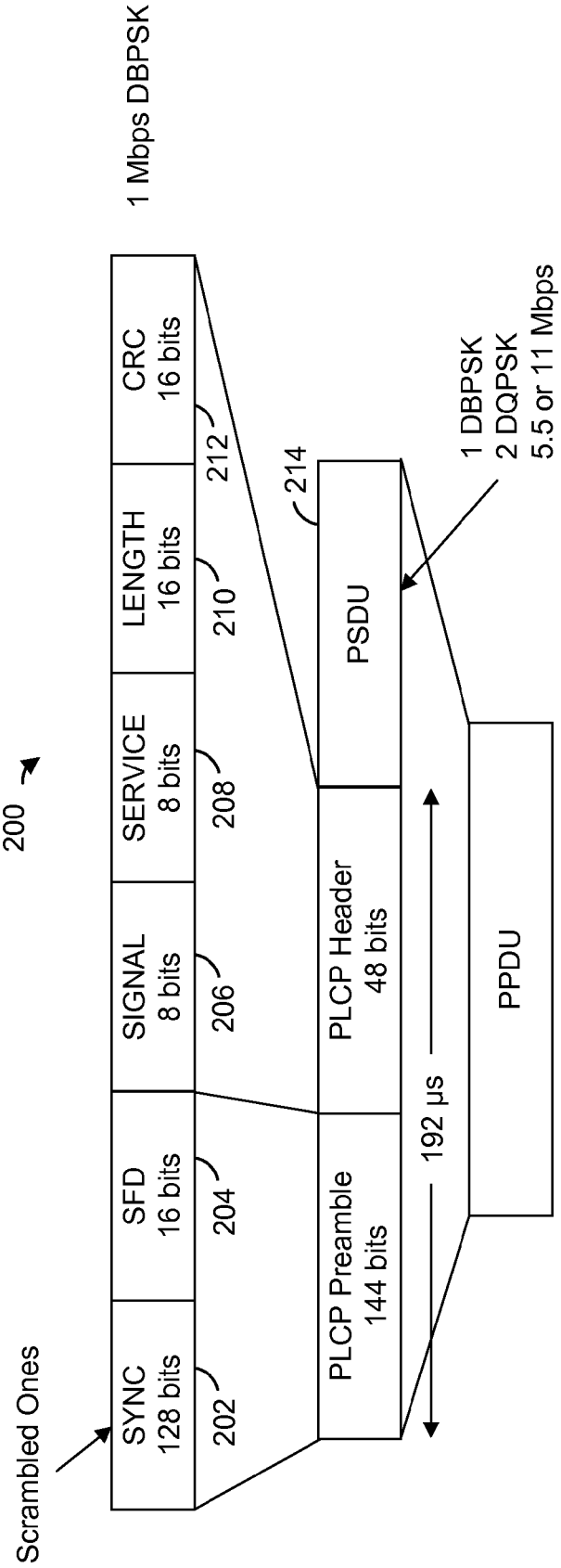


FIG. 6

PRIOR ART

FIG. 7

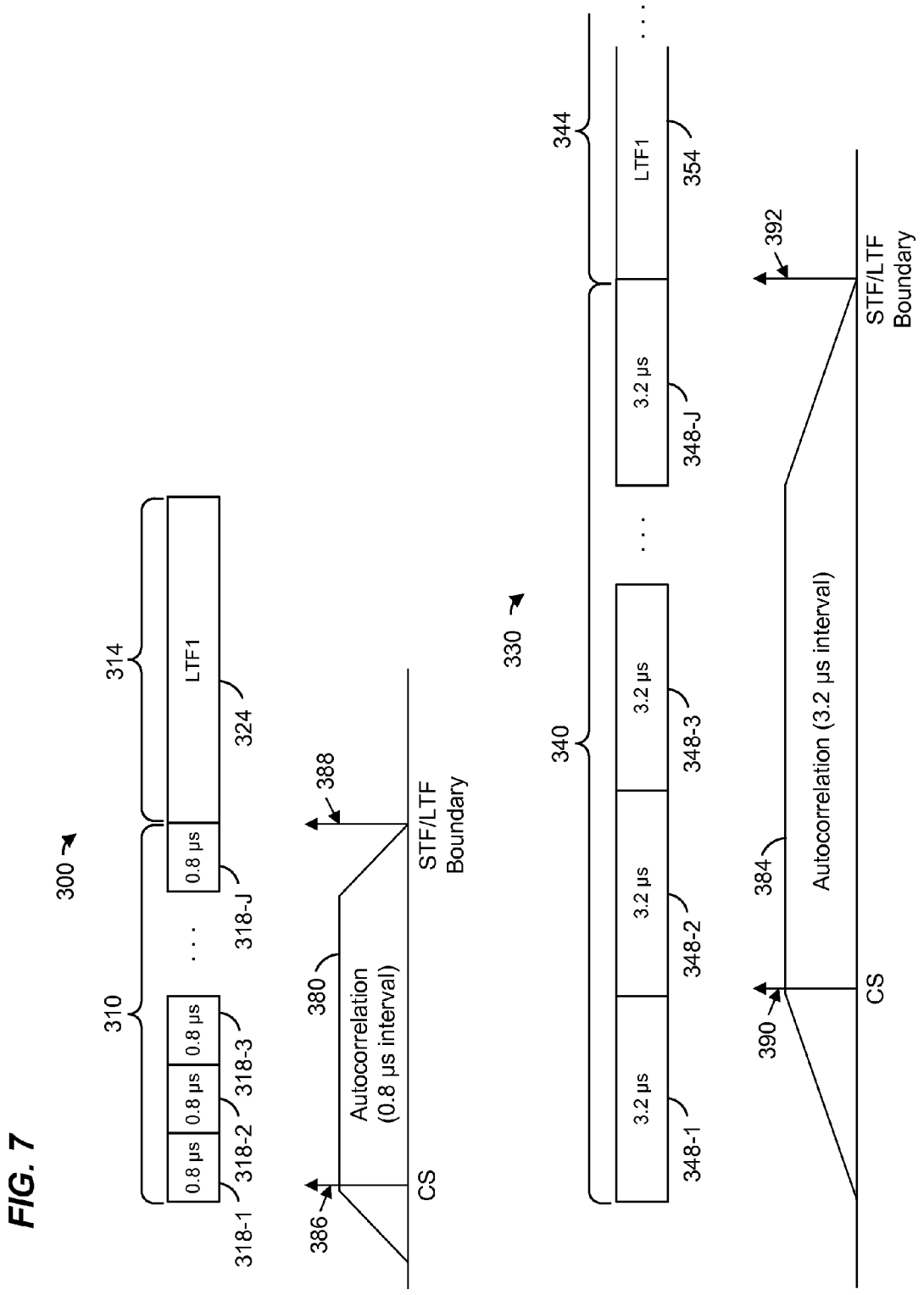

300
310
314
0.8 µs
0.8 µs
0.8 µs
0.8 µs
LTF1
318-1
318-2
318-3
318-J
324
380
388
386
Autocorrelation
(0.8 µs interval)
CS
STF/LTF
Boundary
330
340
344
3.2 µs
3.2 µs
3.2 µs
3.2 µs
LTF1
348-1
348-2
348-3
348-J
354
384
392
390
Autocorrelation (3.2 µs interval)
CS
STF/LTF
Boundary

FIG. 8

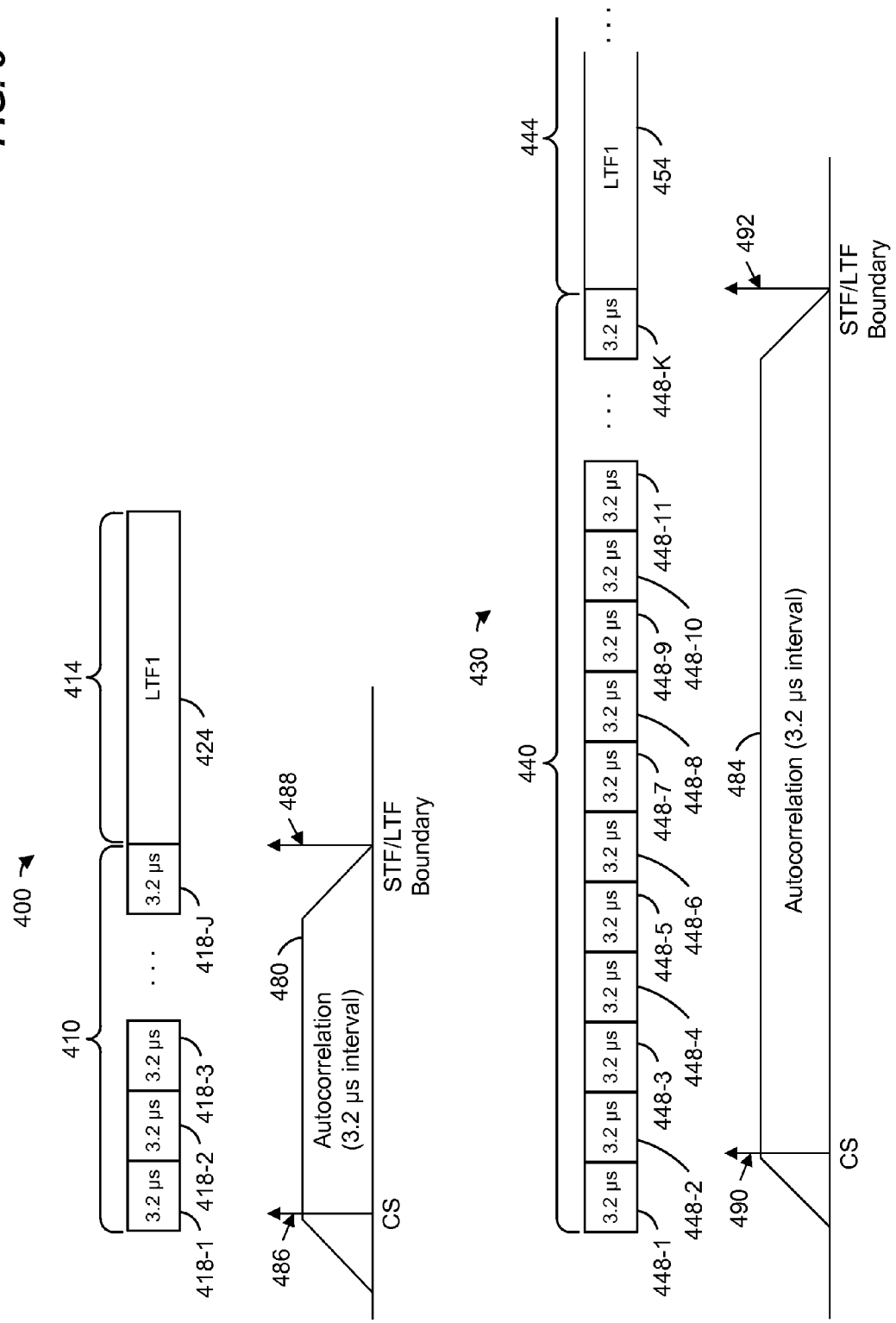
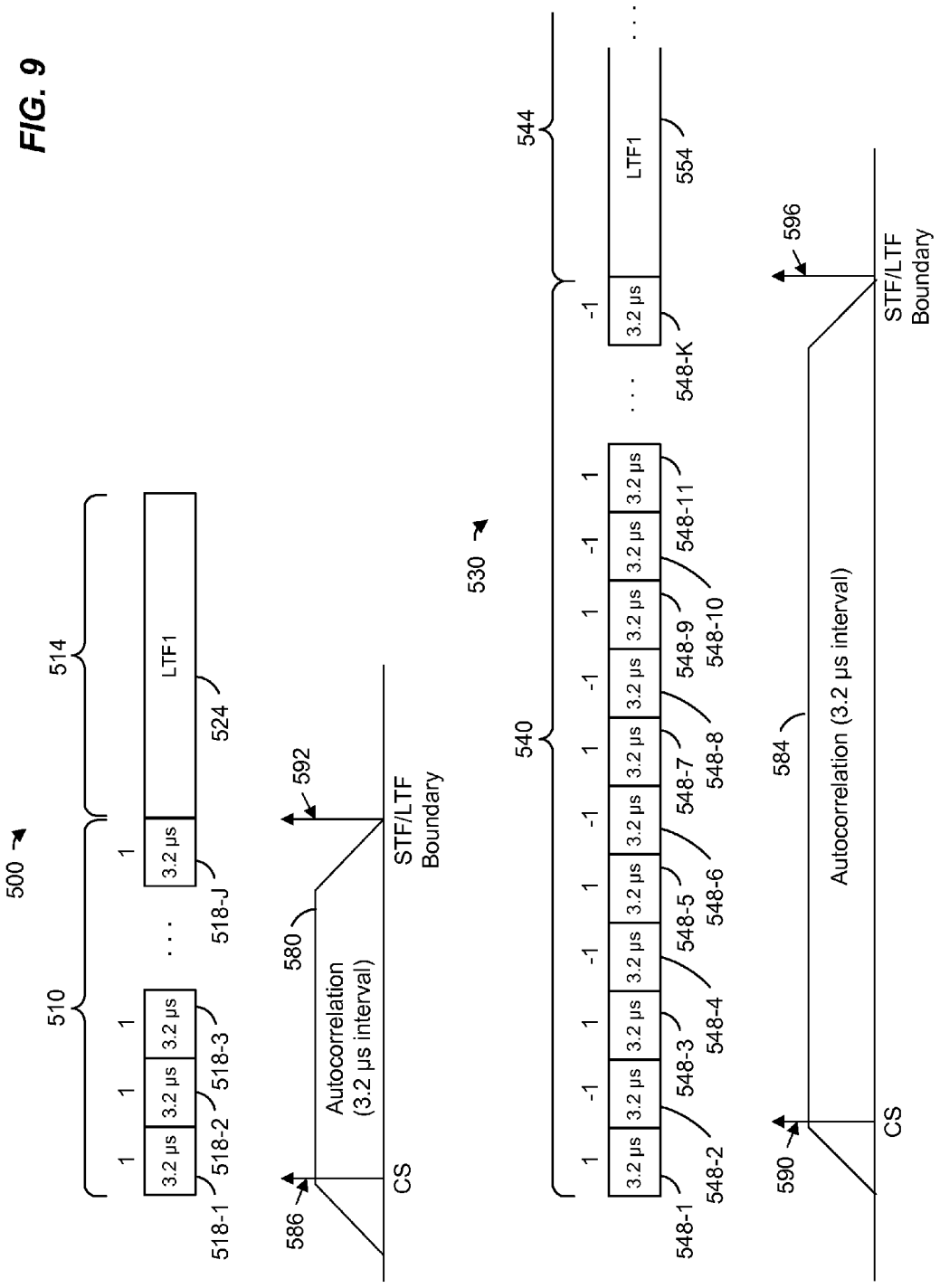

400
410
414
3.2 µs
3.2 µs
3.2 µs
LTF1
418-1
418-2
418-3
418-J
424
480
488
Autocorrelation
(3.2 µs interval)
STF/LTF
Boundary
486
CS
430
440
444
448-1
448-2
448-3
448-4
448-5
448-6
448-7
448-8
448-9
448-10
448-11
448-K
454
484
490
492
Autocorrelation (3.2 µs interval)
STF/LTF
Boundary
CS

FIG. 9


500
510
514
1
1
1
1
3.2 µs
3.2 µs
3.2 µs
LTF1
518-1
518-2
518-3
518-J
524
580
592
586
Autocorrelation
(3.2 µs interval)
CS
STF/LTF
Boundary
530
540
544
-1
548-1
548-2
548-3
548-4
548-5
548-6
548-7
548-8
548-9
548-10
548-11
548-K
554
584
596
590

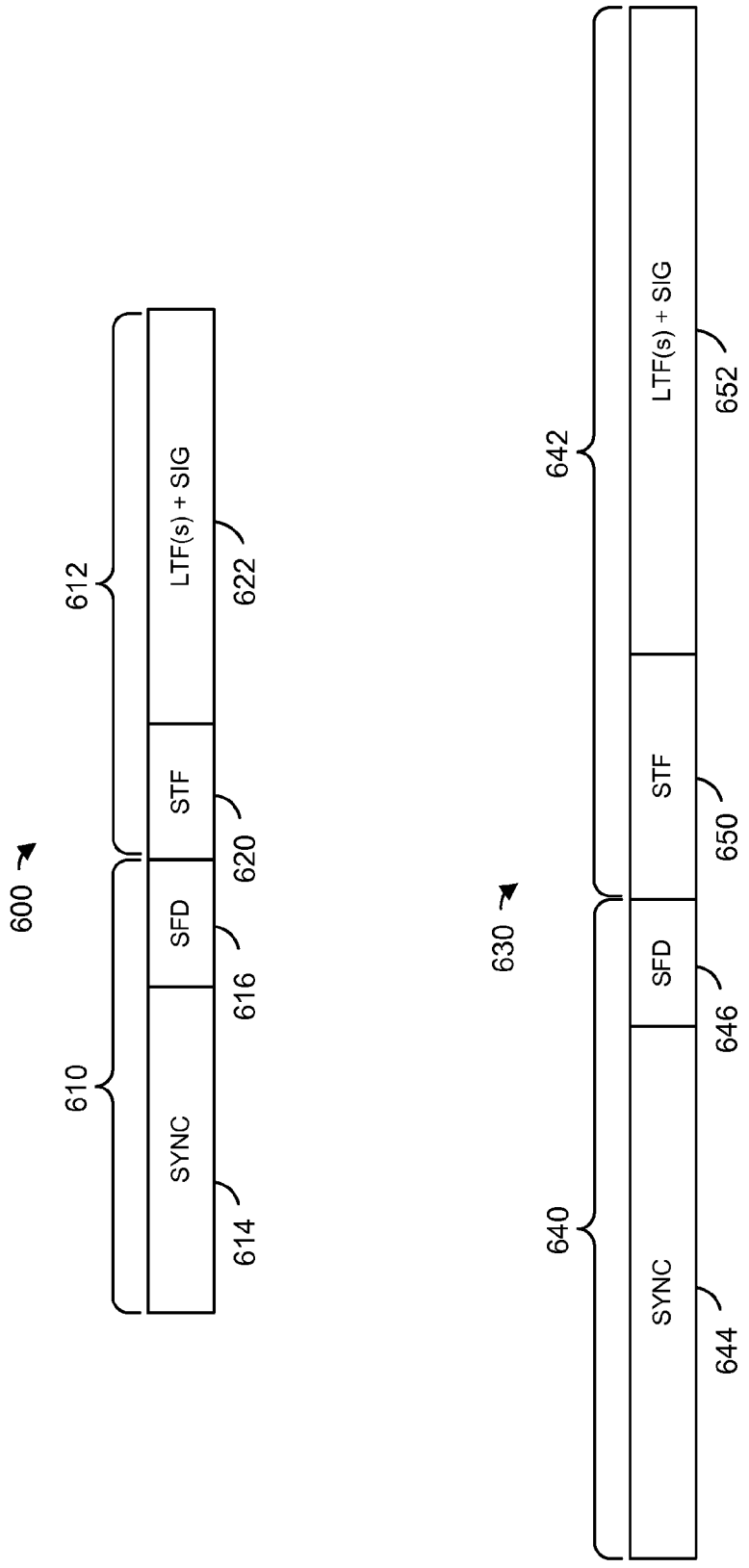
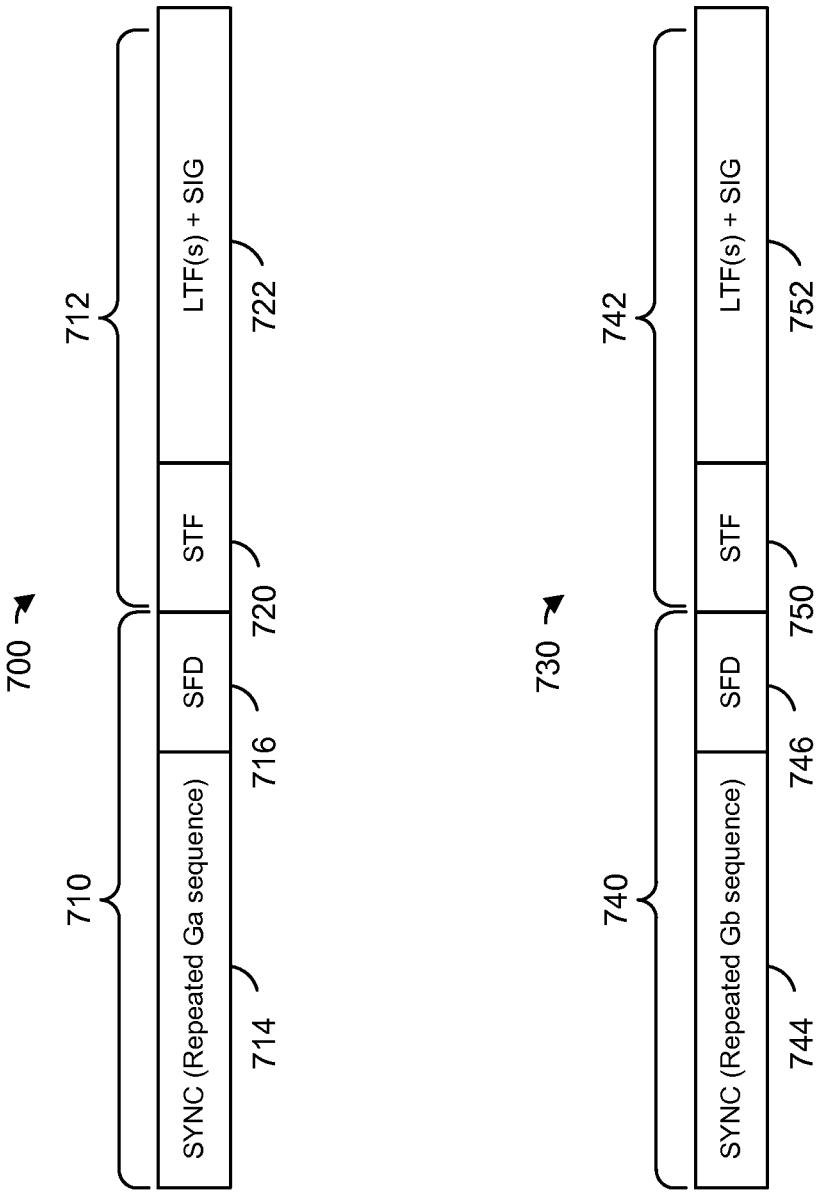

600
610
612
SYNC
SFD
STF
LTF(s) + SIG
614
616
620
622
630
640
642
SYNC
SFD
STF
LTF(s) + SIG
644
646
650
652

FIG. 10

FIG. 11


700
710
712
SYNC (Repeated Ga sequence)
SFD
STF
LTF(s) + SIG
714
716
720
722
730
740
742
SYNC (Repeated Gb sequence)
SFD
STF
LTF(s) + SIG
744
746
750
752

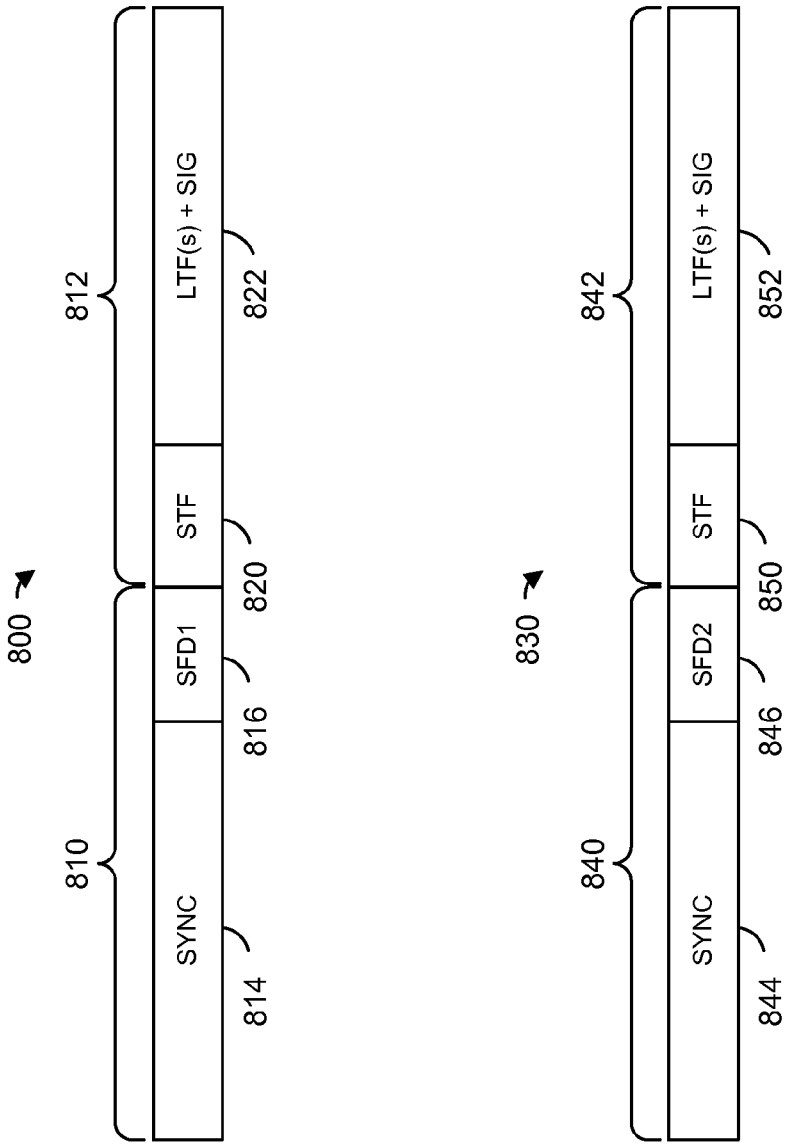

800
810
812
SYNC
SFD1
STF
LTF(s) + SIG
814
816
820
822
830
840
842
SYNC
SFD2
STF
LTF(s) + SIG
844
846
850
852

FIG. 12

FIG. 13

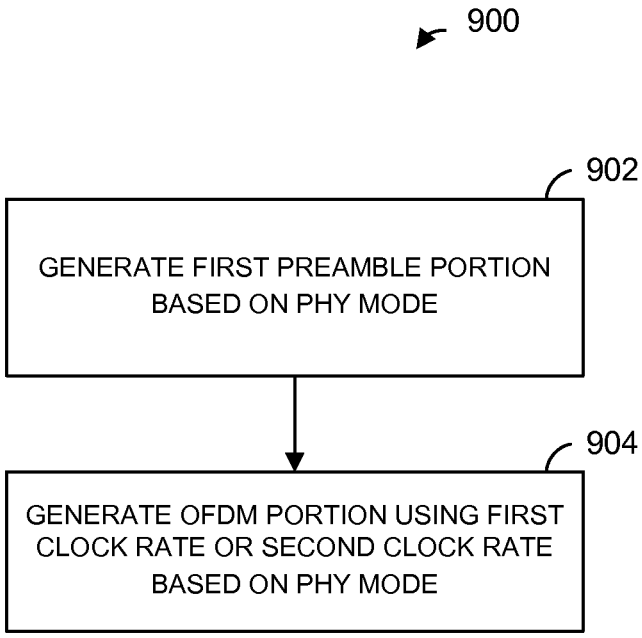

900
902
GENERATE FIRST PREAMBLE PORTION BASED ON PHY MODE
904
GENERATE OFDM PORTION USING FIRST CLOCK RATE OR SECOND CLOCK RATE BASED ON PHY MODE

FIG. 14

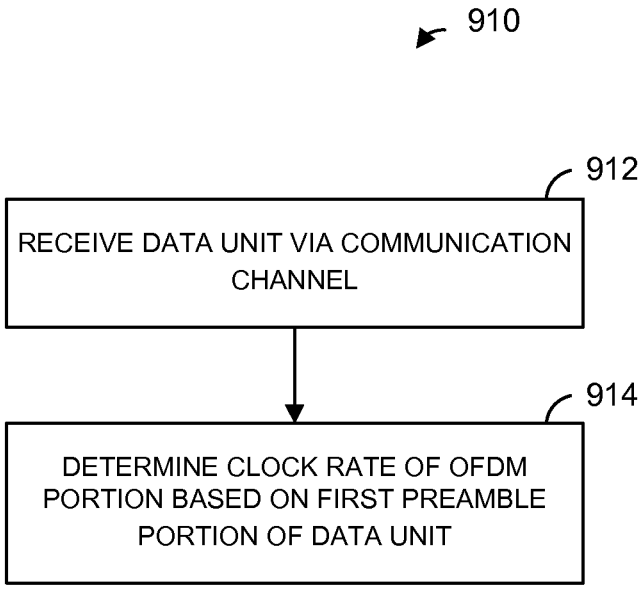

910
912
RECEIVE DATA UNIT VIA COMMUNICATION CHANNEL
914
DETERMINE CLOCK RATE OF OFDM PORTION BASED ON FIRST PREAMBLE PORTION OF DATA UNIT

FIG. 15

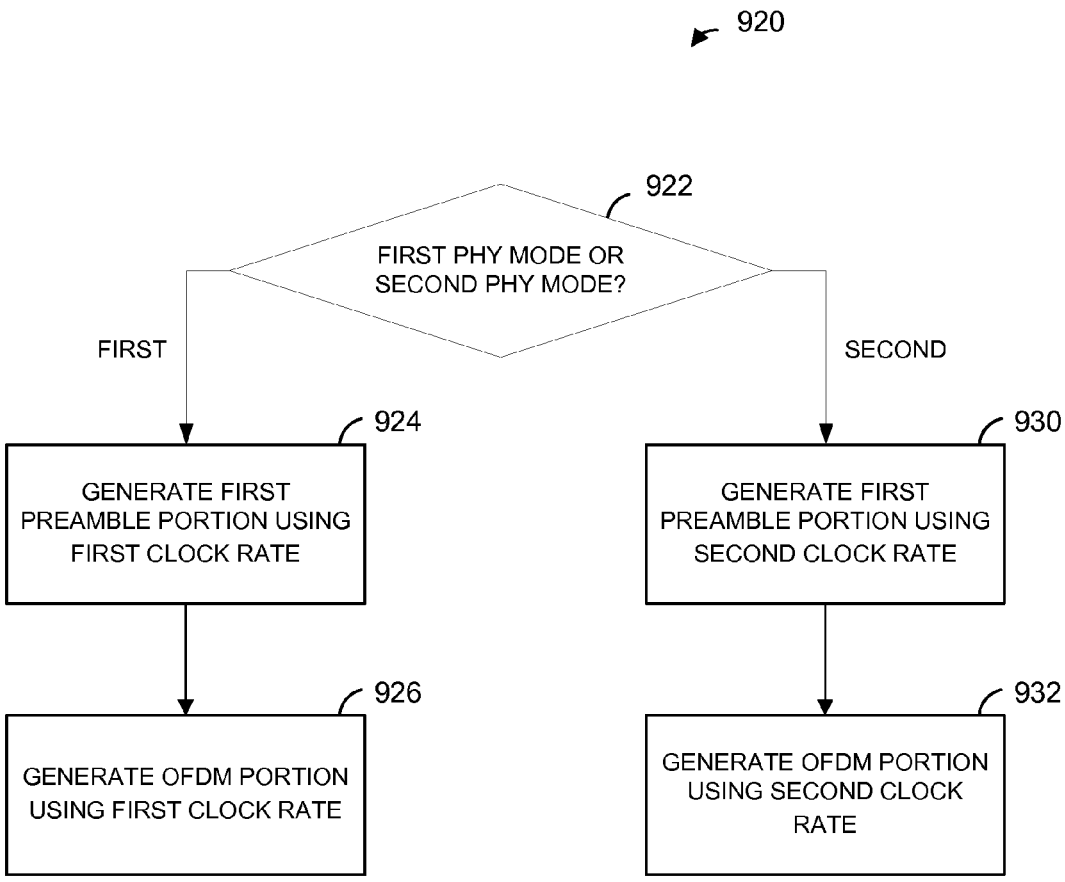

920
922
FIRST PHY MODE OR SECOND PHY MODE?
FIRST
SECOND
924
GENERATE FIRST PREAMBLE PORTION USING FIRST CLOCK RATE
926
GENERATE OFDM PORTION USING FIRST CLOCK RATE
930
GENERATE FIRST PREAMBLE PORTION USING SECOND CLOCK RATE
932
GENERATE OFDM PORTION USING SECOND CLOCK RATE

FIG. 16

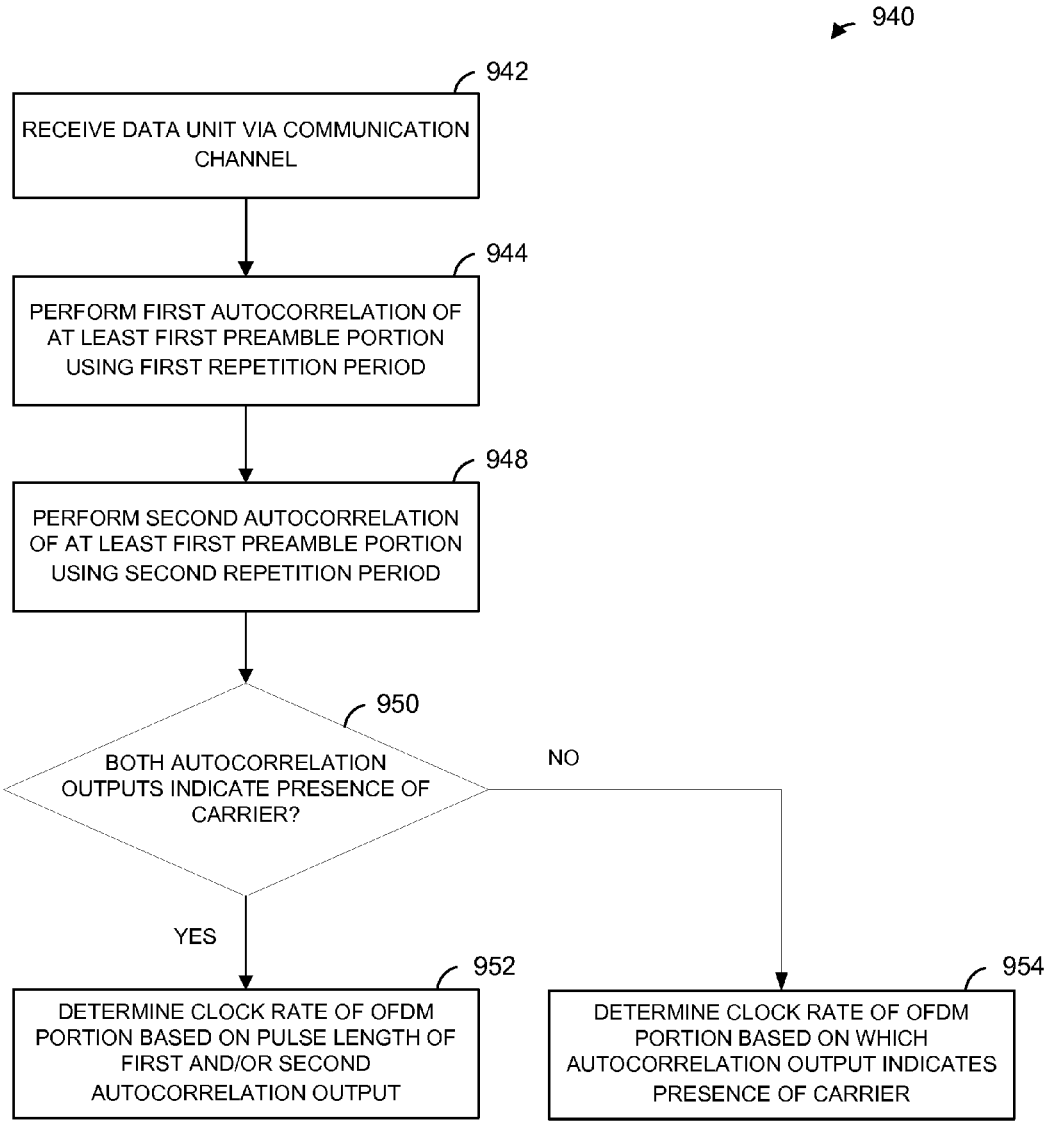

940
942
RECEIVE DATA UNIT VIA COMMUNICATION CHANNEL
944
PERFORM FIRST AUTOCORRELATION OF AT LEAST FIRST PREAMBLE PORTION USING FIRST REPETITION PERIOD
948
PERFORM SECOND AUTOCORRELATION OF AT LEAST FIRST PREAMBLE PORTION USING SECOND REPETITION PERIOD
950
BOTH AUTOCORRELATION OUTPUTS INDICATE PRESENCE OF CARRIER?
NO
YES
952
DETERMINE CLOCK RATE OF OFDM PORTION BASED ON PULSE LENGTH OF FIRST AND/OR SECOND AUTOCORRELATION OUTPUT
954
DETERMINE CLOCK RATE OF OFDM PORTION BASED ON WHICH AUTOCORRELATION OUTPUT INDICATES PRESENCE OF CARRIER

FIG. 17

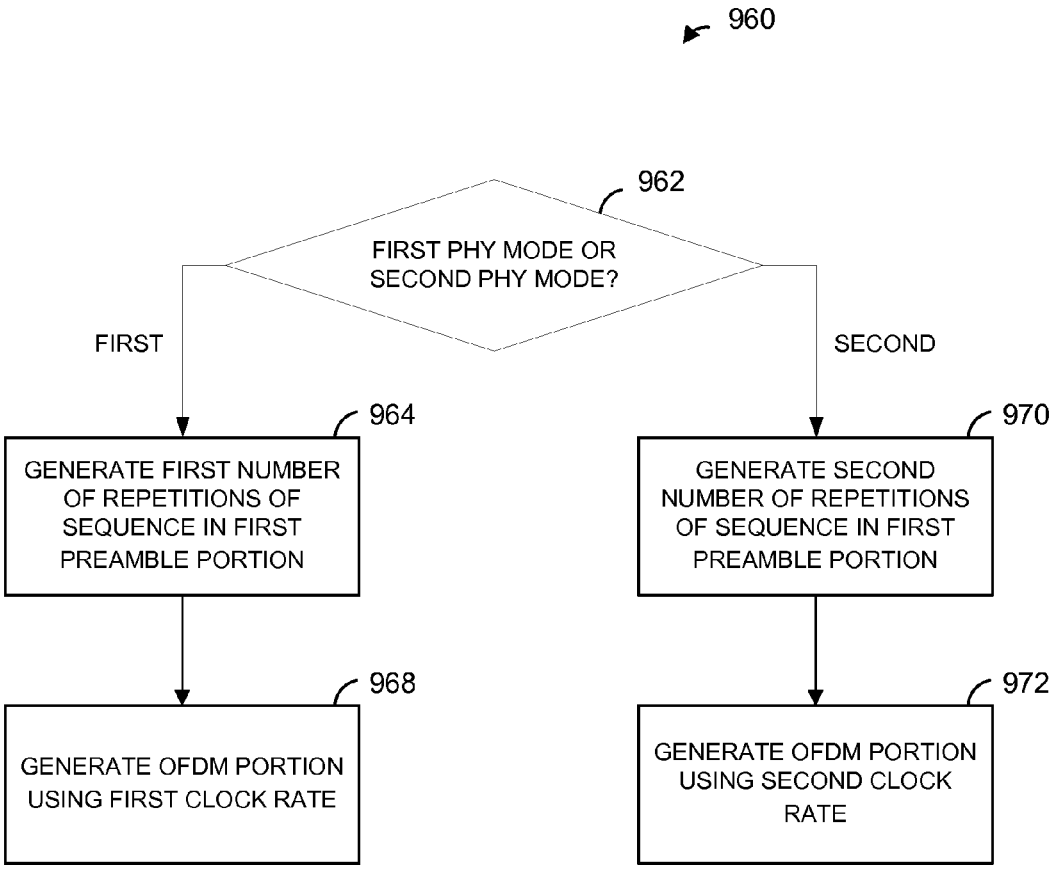

960
962
FIRST PHY MODE OR SECOND PHY MODE?
FIRST
SECOND
964
GENERATE FIRST NUMBER OF REPETITIONS OF SEQUENCE IN FIRST PREAMBLE PORTION
970
GENERATE SECOND NUMBER OF REPETITIONS OF SEQUENCE IN FIRST PREAMBLE PORTION
968
GENERATE OFDM PORTION USING FIRST CLOCK RATE
972
GENERATE OFDM PORTION USING SECOND CLOCK RATE

FIG. 18

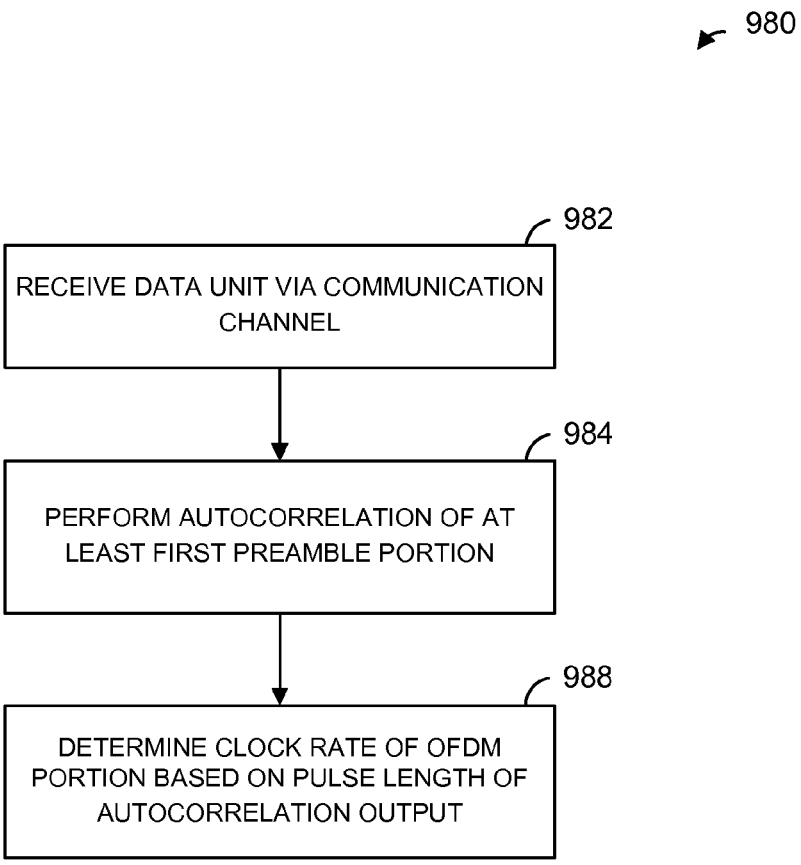

980
982
RECEIVE DATA UNIT VIA COMMUNICATION CHANNEL
984
PERFORM AUTOCORRELATION OF AT LEAST FIRST PREAMBLE PORTION
988
DETERMINE CLOCK RATE OF OFDM PORTION BASED ON PULSE LENGTH OF AUTOCORRELATION OUTPUT

FIG. 19

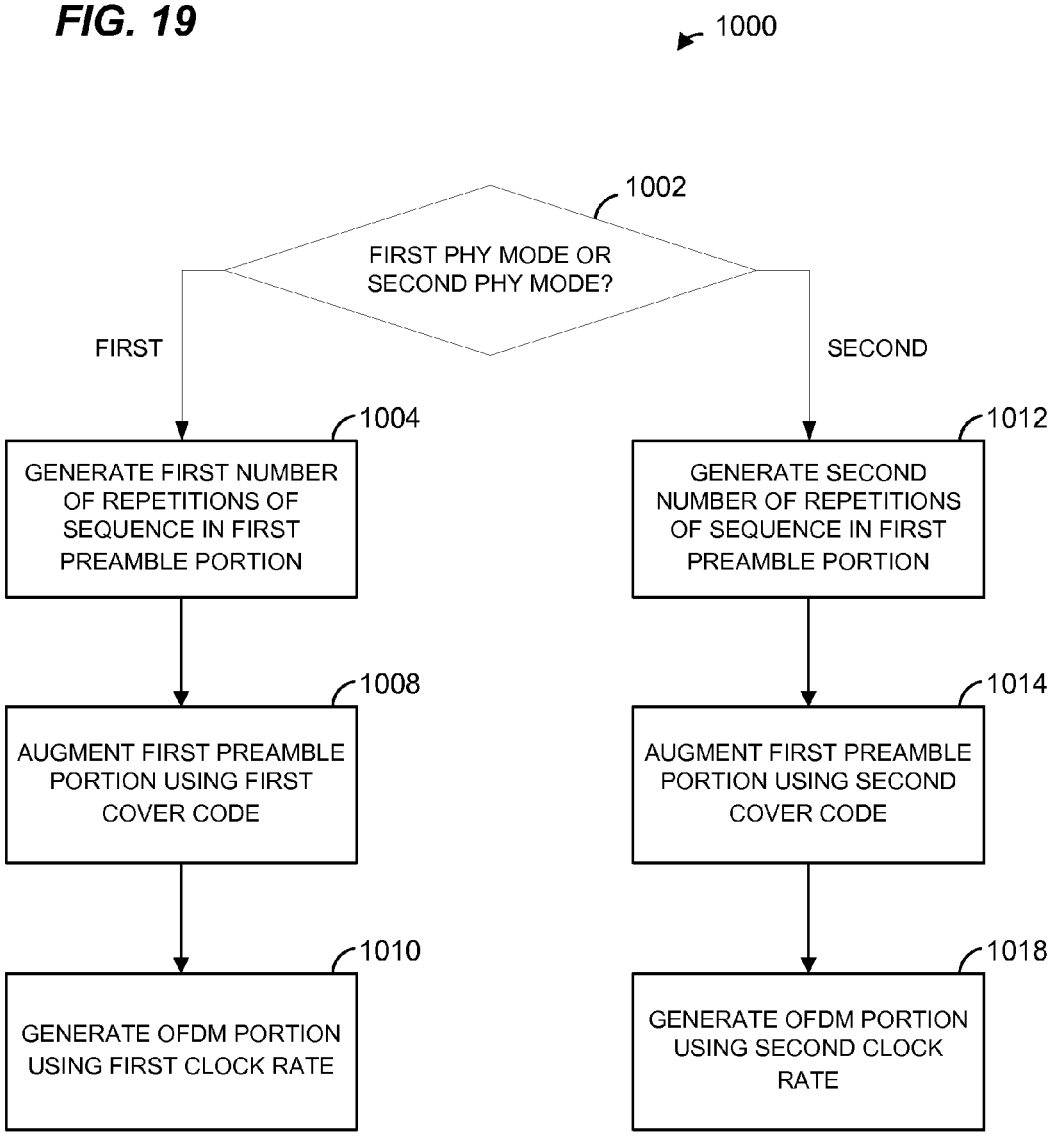

1000
1002
FIRST PHY MODE OR SECOND PHY MODE?
FIRST
SECOND
1004
GENERATE FIRST NUMBER OF REPETITIONS OF SEQUENCE IN FIRST PREAMBLE PORTION
1008
AUGMENT FIRST PREAMBLE PORTION USING FIRST COVER CODE
1010
GENERATE OFDM PORTION USING FIRST CLOCK RATE
1012
GENERATE SECOND NUMBER OF REPETITIONS OF SEQUENCE IN FIRST PREAMBLE PORTION
1014
AUGMENT FIRST PREAMBLE PORTION USING SECOND COVER CODE
1018
GENERATE OFDM PORTION USING SECOND CLOCK RATE

FIG. 20

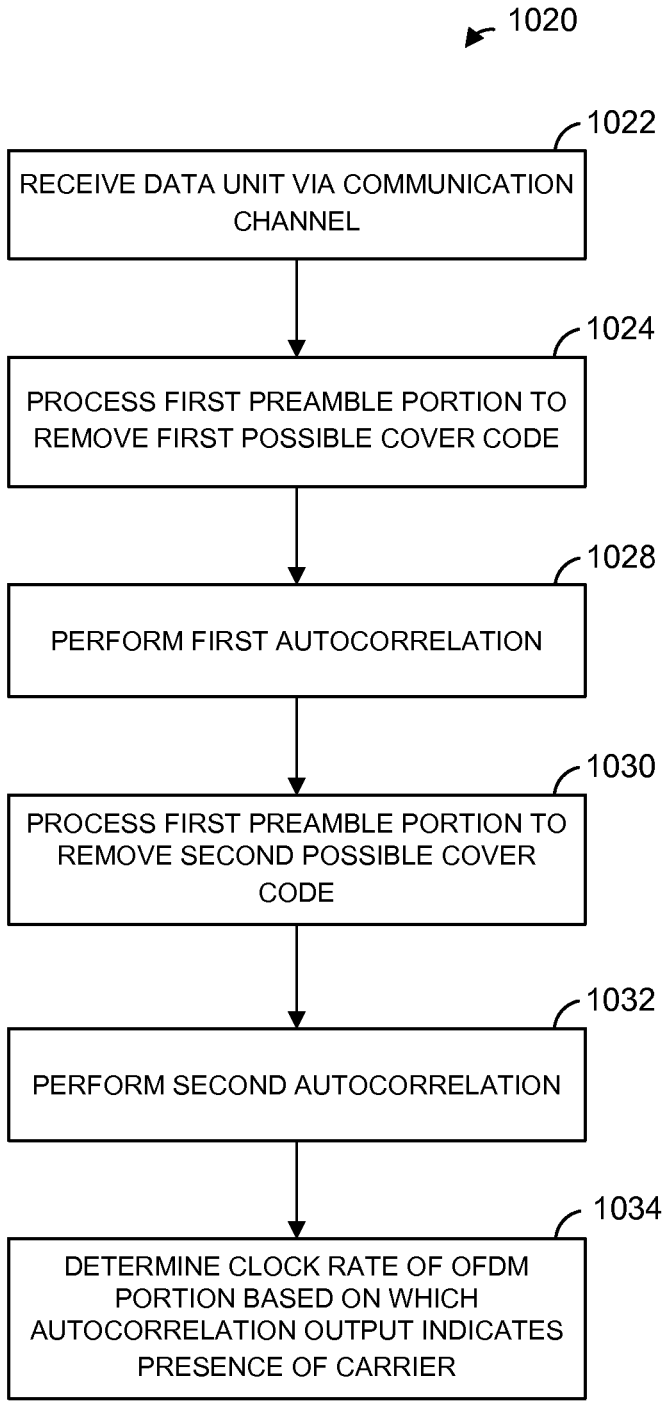

1020
1022
RECEIVE DATA UNIT VIA COMMUNICATION CHANNEL
1024
PROCESS FIRST PREAMBLE PORTION TO REMOVE FIRST POSSIBLE COVER CODE
1028
PERFORM FIRST AUTOCORRELATION
1030
PROCESS FIRST PREAMBLE PORTION TO REMOVE SECOND POSSIBLE COVER CODE
1032
PERFORM SECOND AUTOCORRELATION
1034
DETERMINE CLOCK RATE OF OFDM PORTION BASED ON WHICH AUTOCORRELATION OUTPUT INDICATES PRESENCE OF CARRIER

FIG. 21

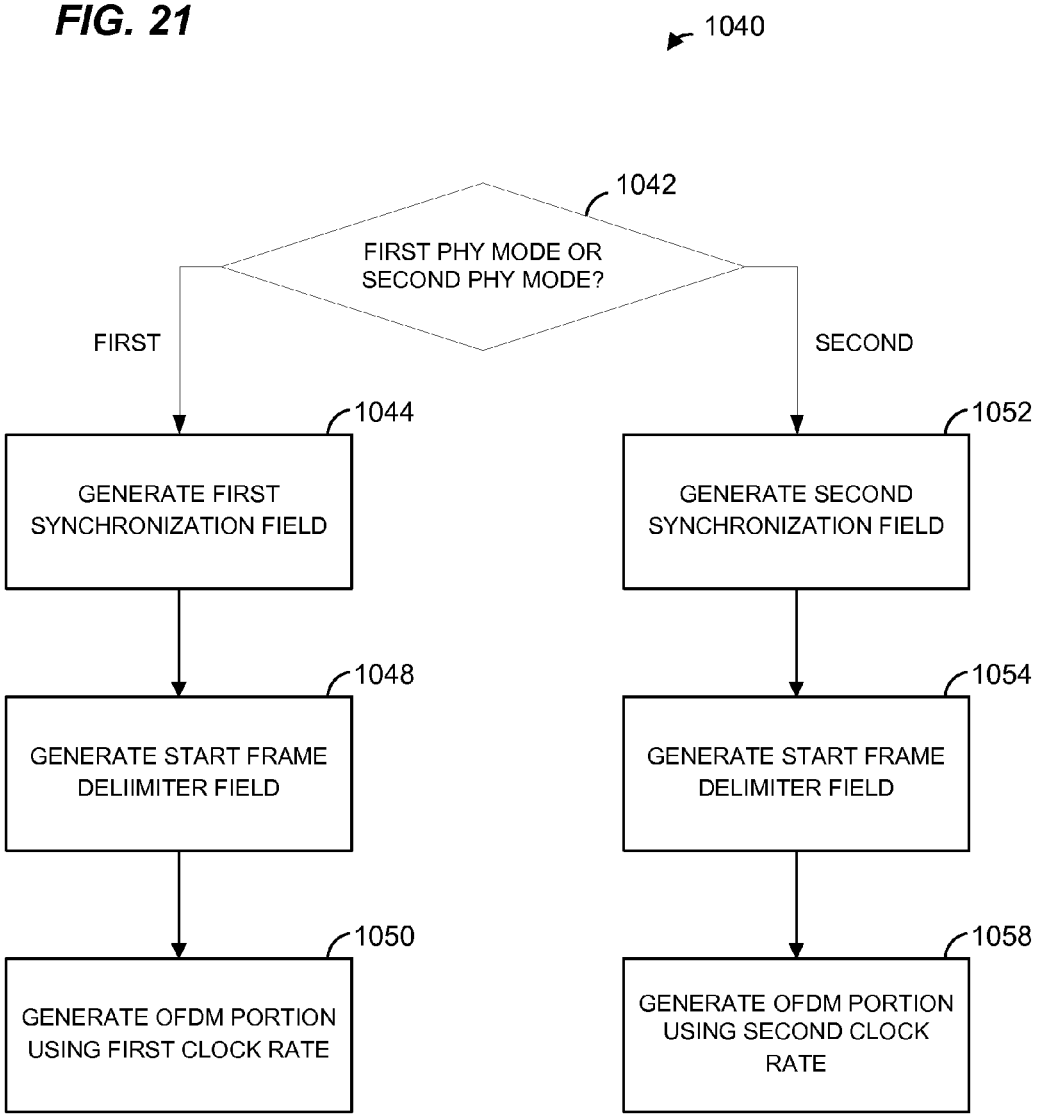

1040
1042
FIRST PHY MODE OR SECOND PHY MODE?
FIRST
SECOND
1044
GENERATE FIRST SYNCHRONIZATION FIELD
1048
GENERATE START FRAME DELIIMITER FIELD
1050
GENERATE OFDM PORTION USING FIRST CLOCK RATE
1052
GENERATE SECOND SYNCHRONIZATION FIELD
1054
GENERATE START FRAME DELIMITER FIELD
1058
GENERATE OFDM PORTION USING SECOND CLOCK RATE

FIG. 22

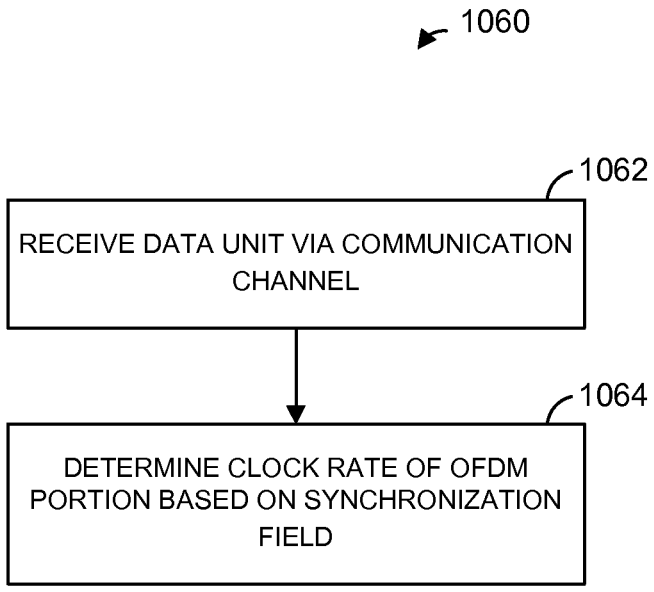

1060
1062
RECEIVE DATA UNIT VIA COMMUNICATION CHANNEL
1064
DETERMINE CLOCK RATE OF OFDM PORTION BASED ON SYNCHRONIZATION FIELD

FIG. 23

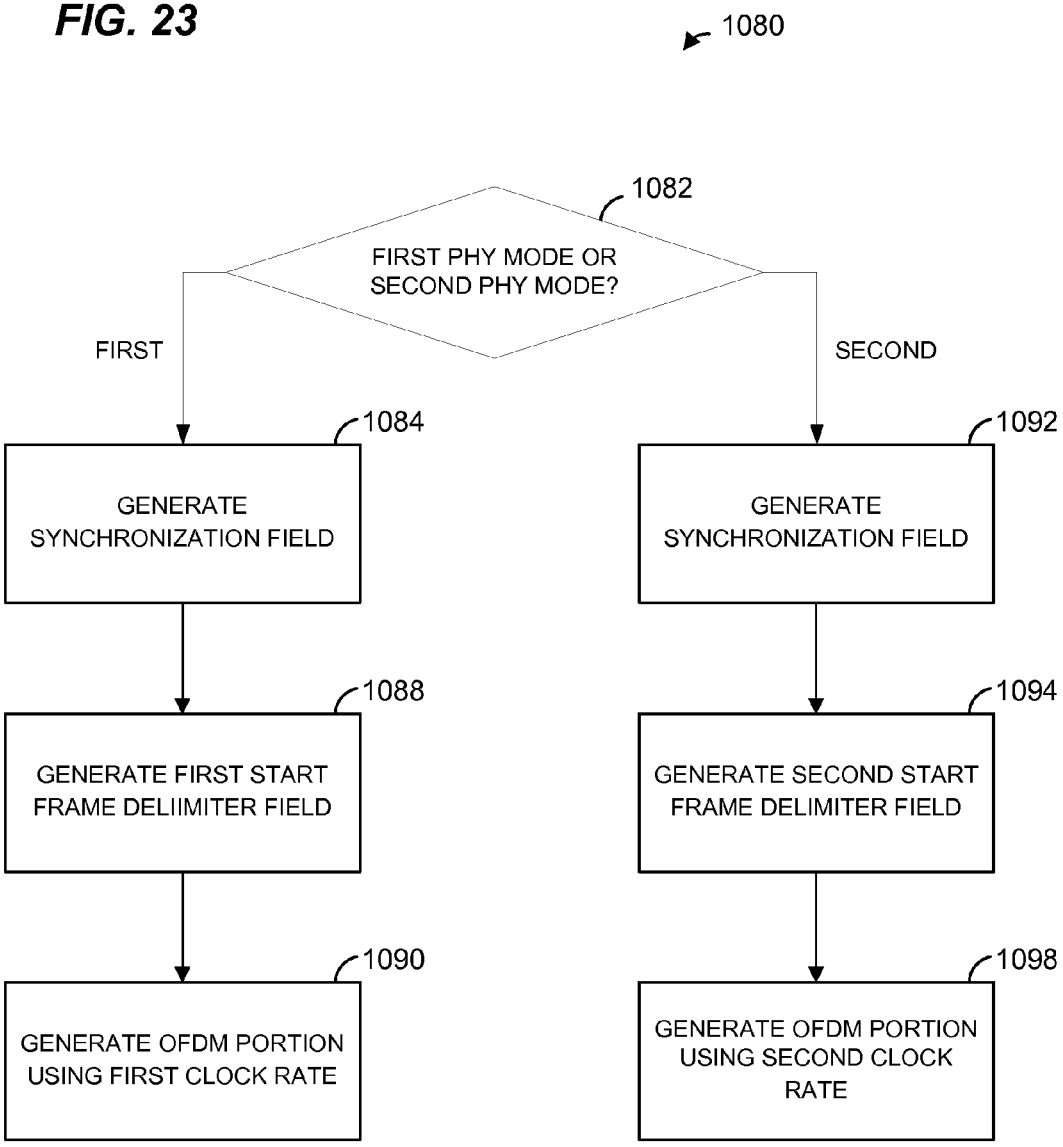
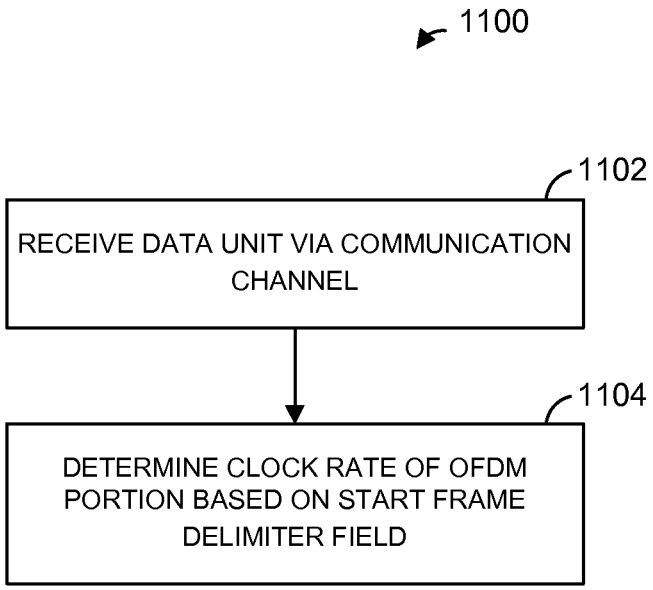

1080
1082
FIRST PHY MODE OR SECOND PHY MODE?
FIRST
SECOND
1084
GENERATE SYNCHRONIZATION FIELD
1088
GENERATE FIRST START FRAME DELIIMITER FIELD
1090
GENERATE OFDM PORTION USING FIRST CLOCK RATE
1092
GENERATE SYNCHRONIZATION FIELD
1094
GENERATE SECOND START FRAME DELIMITER FIELD
1098
GENERATE OFDM PORTION USING SECOND CLOCK RATE

FIG. 24


1100
1102
RECEIVE DATA UNIT VIA COMMUNICATION CHANNEL
1104
DETERMINE CLOCK RATE OF OFDM PORTION BASED ON START FRAME DELIMITER FIELD

MULTI-CLOCK PHYSICAL LAYER [[PHY] PREAMBLE DESIGN AND DETECTION

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of U.S. patent application Ser. No. 13/365,963, entitled "Multi-Clock PHY Preamble Design and Detection" and filed on Feb. 3, 2012, which claims the benefit of U.S. Provisional Patent Application No. 61/441,610, entitled "Multi-Clock PHY Preamble Design and Detection" and filed on Feb. 10, 2011. The disclosures of both of the above-identified applications are hereby incorporated herein by reference.

This application is also related to the commonly-owned U.S. patent application Ser. No. 13/365,950 (now issued as U.S. Pat. No. 8,644,128), entitled "Multi-Clock PHY Preamble Design and Detection" and filed on Feb. 3, 2012, which is hereby incorporated by reference herein.

FIELD OF THE DISCLOSURE

The present disclosure relates generally to communication networks and, more particularly, to wireless local area networks including physical layer modes with multiple clock rates.

BACKGROUND

The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

When operating in an infrastructure mode, wireless local area networks (WLANs) typically include an access point (AP) and one or more client stations. WLANs have evolved rapidly over the past decade. Development of WLAN standards such as the Institute for Electrical and Electronics Engineers (IEEE) 802.11a, 802.11b, 802.11g, and 802.11n Standards has improved single-user peak data throughput. For example, the IEEE 802.11b Standard specifies a single-user peak throughput of 11 megabits per second (Mbps), the IEEE 802.11a and 802.11g Standards specify a single-user peak throughput of 54 Mbps, the IEEE 802.11n Standard specifies a single-user peak throughput of 600 Mbps, and the IEEE 802.11ac Standard specifies a single-user peak throughput in the Gbps range.

Work has begun on two new standards, IEEE 802.11 ah and IEEE 802.11af, each of which will specify wireless network operation in sub-1 GHz frequencies. Low frequency communication channels are generally characterized by better propagation qualities and extended propagation ranges compared to higher frequency communication channels. In the past, sub-1 GHz frequency ranges have not been utilized for wireless communication networks because such frequencies were reserved for other applications (e.g., licensed TV frequency bands, radio frequency band, etc.). There are few frequency bands in the sub-1 GHz range that remain unlicensed, with different unlicensed frequencies in different geographical regions. The IEEE 802.11ah Standard will specify wireless operation in available unlicensed sub-1 GHz frequency bands. The IEEE 802.11af Standard will specify wireless operation in TV White Space (TVWS), i.e., unused TV channels in sub-1 GHz frequency bands.

SUMMARY

In an embodiment, a method for detecting, at a first communication device, a clock rate of a physical layer (PHY) data unit, includes receiving, at the first communication device, the PHY data unit from a second communication device via a communication channel. The PHY data unit includes (i) a first portion and (ii) a second portion following the first portion. The method also includes processing, at the first communication device, the first portion of the PHY data unit. Processing the first portion of the PHY data unit includes performing one or more autocorrelations to generate one or more respective autocorrelation outputs. The method also includes determining, at the first communication device and based on at least one of the one or more autocorrelation outputs, a clock rate of the second portion of the PHY data unit.

In another embodiment, a communication device includes a network interface device configured to receive a PHY data unit via a communication channel, wherein the PHY data unit includes (i) a first portion and (ii) a second portion following the first portion. The network device is also configured to process the first portion of the PHY data unit at least in part by performing one or more autocorrelations to generate one or more respective autocorrelation outputs, and determine, based on at least one of the one or more autocorrelation outputs, a clock rate of the second portion of the PHY data unit.

In another embodiment, a tangible, non-transitory computer-readable medium stores instructions that, when executed by one or more processors of a communication device, cause the one or more processors to process a PHY data unit received via a communication channel. The PHY data unit includes (i) a first portion and (ii) a second portion following the first portion, and the instructions cause the one or more processors to process the PHY data unit at least by performing one or more autocorrelations to generate one or more respective autocorrelation outputs. The instructions also cause the one or more processors to determine, based on at least one of the one or more autocorrelation outputs, a clock rate of the second portion of the PHY data unit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an example wireless local area network (WLAN), according to an embodiment.

FIG. **2** is a diagram of a prior art orthogonal frequency division multiplexing (OFDM) short range data unit that an AP and/or client station is configured to transmit via a communication channel, according to an embodiment.

FIG. **3** is a diagram of a prior art OFDM short range data unit that an AP and/or client station is configured to transmit via a communication channel, according to another embodiment.

FIG. **4** is a diagram of a prior art OFDM short range data unit that an AP and/or client station is configured to transmit via a communication channel, according to another embodiment.

FIG. **5** is a diagram of a prior art OFDM short range data unit that an AP and/or client station is configured to transmit via a communication channel, according to another embodiment.

FIG. **6** is a diagram of a prior art single carrier (SC) short range data unit that an AP and/or client station is configured to transmit via a communication channel, according to an embodiment.

FIG. **7** is a diagram of a first example preamble design and corresponding auto-detection technique for determining a data unit clock rate, according to an embodiment.

FIG. **8** is a diagram of a second example preamble design and corresponding auto-detection technique for determining a data unit clock rate, according to an embodiment.

FIG. **9** is a diagram of a third example preamble design and corresponding auto-detection technique for determining a data unit clock rate, according to an embodiment.

FIG. **10** is a diagram of a fourth example preamble design corresponding to an auto-detection technique for determining a data unit clock rate, according to an embodiment.

FIG. **11** is a diagram of a fifth example preamble design corresponding to an auto-detection technique for determining a data unit clock rate, according to an embodiment.

FIG. **12** is a diagram of a sixth example preamble design corresponding to an auto-detection technique for determining a data unit clock rate, according to an embodiment.

FIG. **13** is a flow diagram of an example method for generating a data unit according to the first, second, third, fourth, fifth, or sixth example preamble design, according to an embodiment.

FIG. **14** is a flow diagram of an example method for auto-detecting a clock rate of a data unit generated according to the first, second, third, fourth, fifth, or sixth example preamble design, according to an embodiment.

FIG. **15** is a flow diagram of an example method for generating a data unit according to the first example preamble design, according to an embodiment.

FIG. **16** is a flow diagram of an example method for auto-detecting a clock rate of a data unit generated according to the first example preamble design, according to an embodiment.

FIG. **17** is a flow diagram of an example method for generating a data unit according to the second example preamble design, according to an embodiment.

FIG. **18** is a flow diagram of an example method for auto-detecting a clock rate of a data unit generated according to the second example preamble design, according to an embodiment.

FIG. **19** is a flow diagram of an example method for generating a data unit according to the third example preamble design, according to an embodiment.

FIG. **20** is a flow diagram of an example method for auto-detecting a clock rate of a data unit generated according to the third example preamble design, according to an embodiment.

FIG. **21** is a flow diagram of an example method for generating a data unit according to the fourth or fifth example preamble design, according to an embodiment.

FIG. **22** is a flow diagram of an example method for auto-detecting a clock rate of a data unit generated according to the fourth or fifth example preamble design, according to an embodiment.

FIG. **23** is a flow diagram of an example method for generating a data unit according to the sixth example preamble design, according to an embodiment.

FIG. **24** is a flow diagram of an example method for auto-detecting a clock rate of a data unit generated according to the sixth example preamble design, according to an embodiment.

DETAILED DESCRIPTION

In embodiments described below, a wireless network device such as an access point (AP) of a wireless local area network (WLAN) transmits data streams to, and/or receives data streams from, one or more client stations. The AP is configured to communicate with client stations according to at least a first communication protocol. The first communication protocol defines operation in a sub-1 GHz frequency range, and is typically used for applications requiring longer range wireless communication (as compared to WLAN systems that conform to the IEEE 802.11a, 802.11b, 802.11g, and 802.11n Standards) with relatively low data rates (as compared to WLAN systems that conform to the IEEE 802.11a, 802.11b, 802.11g, and 802.11n Standards). The first communication protocol (e.g., IEEE 802.11 of or IEEE 802.11 ah) is referred to herein as a "long range" communication protocol. In some embodiments, the AP is also configured to communicate with client stations according to one or more other communication protocols which define operation in generally higher frequency ranges and are typically used for closer-range communications with higher data rates. The higher frequency communication protocols (e.g., IEEE 802.11a, IEEE 802.11n, and/or IEEE 802.11ac) are collectively referred to herein as "short range" communication protocols.

In some embodiments, the physical layer (PHY) data units conforming to the long range communication protocol ("long range data units") are the same as or similar to data units conforming to a short range communication protocol ("short range data units"), but are generated using a lower clock rate. For example, in an embodiment, a device (e.g., an AP) generates a long range data unit by down-sampling or "down-clocking" a clock rate used to generate the short range data units. Accordingly, in some embodiments, a single communication device is capable of generating multiple types of data units (e.g., long range and short range data units), each type having a similar format but generated using a different clock rate. Thus, in some embodiments, two or more differently clocked data units corresponding to two or more different PHY modes coexist at the same time in the same region. In some embodiments, a single WLAN includes communications conforming to two or more long range communication modes, each utilizing data units that are down-clocked from a short range data unit (e.g., first and second PHY modes down-clocked to ¼ and ⅛, respectively, of the IEEE 802.11n data unit clock rate, in an embodiment).

All else being equal, an orthogonal frequency division multiplexing (OFDM) symbol generated using a faster clock is shorter in duration than an OFDM symbol generated using a slower clock. To properly demodulate received data units that include OFDM symbols (e.g., IEEE 802.11a, IEEE 802.11n, IEEE 802.11ac, IEEE 802.11af, and IEEE 802.11 ah data units), a receiving device generally must know the clock rate that the transmitting device used to generate the received data unit. Accordingly, where different clock rates are used for different PHY modes in a single region and at the same time, communication devices without a priori knowledge must determine or auto-detect the clock rate of received data units. Various embodiments of data unit preamble designs, and corresponding receiver techniques for auto-detecting clock rates based on the preamble designs, are disclosed herein.

FIG. **1** is a block diagram of an example wireless local area network (WLAN) **10**, according to an embodiment. An AP **14** includes a host processor **15** coupled to a network interface **16**. The network interface **16** includes a medium access control (MAC) unit **18** and a PHY unit **20**. The PHY unit **20** includes a plurality of transceivers **21**, and the transceivers are coupled to a plurality of antennas **24**. Although three transceivers **21** and three antennas **24** are illustrated in FIG. **1**, the AP **14** can include different numbers (e.g., 1, 2, 4, 5, etc.) of transceivers **21** and antennas **24** in other embodiments.

The WLAN **10** includes a plurality of client stations **25**. Although four client stations **25** are illustrated in FIG. **1**, the

WLAN **10** can include different numbers (e.g., 1, 2, 3, 5, 6, etc.) of client stations **25** in various scenarios and embodiments. The client station **25-1** includes a host processor **26** coupled to a network interface **27**. The network interface **27** includes a MAC unit **28** and a PHY unit **29**. The PHY unit **29** includes a plurality of transceivers **30**, and the transceivers **30** are coupled to a plurality of antennas **34**. Although three transceivers **30** and three antennas **34** are illustrated in FIG. **1**, the client station **25-1** can include different numbers (e.g., 1, 2, 4, 5, etc.) of transceivers **30** and antennas **34** in other embodiments. In an embodiment, one, two, or three of the client stations **25-2**, **25-3**, and **25-4** have a structure the same as or similar to the client station **25-1**. In these embodiments, the client stations **25** are structured the same as or similar to the client station **25-1** and have the same or a different number of transceivers and antennas. For example, the client station **25-2** has only two transceivers and two antennas, in an embodiment.

In various embodiments, the PHY unit **20** of the AP **14** is configured to operate in any of multiple PHY modes. In some embodiments, each PHY mode corresponds to a particular communication protocol, or to a particular mode of a communication protocol. As a result, in some embodiments, each PHY mode corresponds to using a particular clock rate to generate corresponding data units. For example, a first PHY mode corresponds to a short range communication protocol for which the PHY unit **20** generates data units using a first clock rate, and a second PHY mode corresponds to a long range communication protocol for which the PHY unit **20** generates data units using a second clock rate that is down-clocked from the first clock rate, in an embodiment. As another example, a first PHY mode corresponds to a short range communication protocol for which the PHY unit **20** generates data units using a first clock rate, a second PHY mode corresponds to a "regular" mode of a long range communication protocol for which the PHY unit **20** generates data units using a second clock rate that is down-clocked from the first clock rate (e.g., ¼ the first clock rate), and a third PHY mode corresponds to an "extended range" mode of the long range communication protocol for which the PHY unit **20** generates data units using a third clock rate that is further down-clocked from the first clock rate (e.g., ⅛ the first clock rate), in an embodiment.

The transceiver(s) **21** of the AP **14** is/are configured to transmit the generated data units via the antenna(s) **24**. Similarly, the transceiver(s) **21** is/are configured to receive similar data units via the antenna(s) **24**. In various embodiments, the PHY unit **20** of the AP **14** is further configured to process received data units (e.g., data units that conform to any of the communication protocols and PHY modes that the PHY unit **20** supports for transmission).

In some embodiments, the PHY unit **29** of the client station **25-1** is configured to generate data units conforming to only a single PHY mode that corresponds to a particular communication protocol and data unit clock rate. In other embodiments, the PHY unit **29**, in a manner similar to the PHY unit **20**, is configured to generate data units conforming to any of multiple PHY modes, with each PHY mode corresponding to a particular communication protocol (or a particular mode of a communication protocol) and a particular data unit clock rate.

The transceiver(s) **30** is/are configured to transmit the generated data units via the antenna(s) **34**. Similarly, the transceiver(s) **30** is/are configured to receive data units via the antenna(s) **34**. The PHY unit **29** of the client station **25-1** is further configured to process received data units (e.g., data units that conform to any of the communication protocols and PHY modes that the PHY unit **29** supports for transmission).

Similar to client station **25-1**, each of client stations **25-2**, **25-3**, and **25-4** is configured to transmit and/or receive data units corresponding to only a single PHY mode, or data units corresponding to any one of multiple PHY modes, in various embodiments. In some embodiments, one or more of the client stations **25-1** through **25-4** is configured to transmit and/or receive data units corresponding to a PHY mode that is not supported by one or more others of the client stations **25-1** through **25-4**. For example, in an embodiment, the client station **25-1** is configured to transmit and/or receive only short range data units clocked at a first rate, while the client station **25-2** is configured to transmit and/or receive only long range data units clocked at a second, slower rate.

FIG. **2** is a diagram of a prior art OFDM short range data unit **100** that an AP (e.g., AP **14** of FIG. **1**) and/or a client station (e.g., client station **25-1** of FIG. **1**) is configured to transmit via a communication channel, according to an embodiment. The data unit **100** conforms to the IEEE 802.11a Standard and occupies a 20 Megahertz (MHz) band. The data unit **100** includes a preamble having a legacy short training field (L-STF) **102**, generally used for packet detection, initial synchronization, and automatic gain control, etc., and a legacy long training field (L-LTF) **104**, generally used for channel estimation and fine synchronization. The data unit **100** also includes a legacy signal field (L-SIG) **106**, used to carry certain PHY parameters of the data unit **100** such as the modulation type and coding rate used to generate the data unit **100**, for example. The data unit **100** also includes a data portion **108**. According to some embodiments and/or scenarios, the data portion **108** includes a service field, a scrambled PHY service data unit (PSDU), tail bits, and padding bits, if needed. The data unit **100** is designed for transmission over one spatial or space-time stream in a single input single output (SISO) channel configuration.

FIG. **3** is a diagram of a prior art OFDM short range data unit **120** that an AP (e.g., AP **14** of FIG. **1**) and/or a client station (e.g., client station **25-1** of FIG. **1**) is configured to transmit via a communication channel, according to another embodiment. The data unit **120** conforms to the IEEE 802.11n Standard, occupies a 20 MHz band, and corresponds to a "mixed" mode designed for scenarios where the WLAN includes both client stations that conform to the IEEE 802.11n Standard and client stations that conform to the IEEE 802.11a Standard but not the IEEE 802.11n Standard. The data unit **120** includes a preamble having an L-STF **122**, an L-LTF **124**, an L-SIG **126**, a high throughput signal field (HT-SIG) **128**, a high throughput short training field (HT-STF) **130**, and M high throughput long training fields (HT-LTFs) **132-1** through **132-M**, where M is an integer which generally corresponds to a number of spatial streams used to transmit the data unit **120** in a multiple input multiple output (MIMO) channel configuration. In particular, according to the IEEE 802.11n Standard, the data unit **120** includes two HT-LTFs **132** if the data unit **120** is transmitted using two spatial streams, and four HT-LTFs **132** if the data unit **120** is transmitted using three or four spatial streams. An indication of the particular number of spatial streams being utilized is included in the HT-SIG **128**. The data unit **120** also includes a high throughput data portion (HT-DATA) **134**.

Within the data unit **120**, L-SIG **126** is modulated according to binary phase shift keying (BPSK), while HT-SIG **128** is modulated according to BPSK on the quadrature axis (Q-BPSK). In other words, the modulation of HT-SIG **128** is rotated by 90 degrees as compared to the modulation of L-SIG **126**. Such modulation allows a receiving device to

determine or auto-detect, without decoding the entire preamble, that the data unit **120** conforms to the IEEE802.11n Standard rather than the IEEE 802.11a Standard.

FIG. **4** is a diagram of a prior art OFDM short range data unit **140** that an AP (e.g., AP **14** of FIG. **1**) and/or a client station (e.g., client station **25-1** of FIG. **1**) is configured to transmit via a communication channel, according to another embodiment. The data unit **140** conforms to the IEEE 802.11n Standard, occupies a 20 MHz band, and corresponds to a "Greenfield" mode designed for scenarios where the WLAN does not include any client stations that conform to the IEEE 802.11a Standard but not the IEEE 802.11n Standard. The data unit **140** includes a preamble having a high throughput Greenfield short training field (HT-GF-STF) **142**, a first high throughput long training field (HT-LTF1) **144**, a HT-SIG **146**, and M HT-LTFs **148-1** through **148**-M, where M is an integer which generally corresponds to a number of spatial streams used to transmit the data unit **140** in a MIMO channel configuration. The data unit **140** also includes a data portion **150**.

FIG. **5** is a diagram of a prior art OFDM short range data unit **170** that an AP (e.g., AP **14** of FIG. **1**) and/or a client station (e.g., client station **25-1** of FIG. **1**) is configured to transmit via a communication channel, according to another embodiment. The data unit **170** conforms to the IEEE 802.11ac Standard and is designed for scenarios where the WLAN includes both client stations that conform to the IEEE 802.11ac Standard and client stations that conform to the IEEE 802.11a Standard but not the IEEE 802.11ac Standard. The data unit **170** occupies a 20 MHz bandwidth. In other embodiments or scenarios, a data unit similar to the data unit **170** occupies a different bandwidth, such as a 40 MHz, an 80 MHz, or a 160 MHz bandwidth. The data unit **170** includes a preamble having an L-STF **172**, an L-LTF **174**, an L-SIG **176**, a first very high throughput signal field (VHT-SIG-A) **178**, a very high throughput short training field (VHT-STF) **180**, M very high throughput long training fields (VHT-LTFs) **182-1** through **182**-M, where M is an integer, and a second very high throughput signal field (VHT-SIG-B) **184**. The data unit **170** also includes a very high throughput data portion (VHT-DATA) **186**. In some embodiments, the data unit **170** is a multi-user data unit transmitted by an AP (e.g., AP **14** of FIG. **1**) which carries information to more than one client station (e.g., one or more of the client stations **25** of FIG. **1**) simultaneously. In such embodiments or scenarios, VHT-SIG-A **178** includes information common to all of the intended client stations, and VHT-SIG-B **184** includes user-specific information for each of the intended client stations.

Within the data unit **170**, L-SIG **176** and VHT-SIG-A **178** are modulated according to BPSK, while VHT-SIG-B **184** is modulated according to Q-BPSK. Similar to the IEEE 802.11n auto-detection feature discussed above, such modulation allows a receiving device to determine or auto-detect, without decoding the entire preamble, that the data unit **170** conforms to the IEEE802.11ac Standard rather than the IEEE 802.11a Standard.

FIG. **6** is a diagram of a prior art single carrier (SC) short range data unit **200** that an AP (e.g., AP **14** of FIG. **1**) and/or a client station (e.g., client station **25-1** of FIG. **1**) is configured to transmit via a communication channel, according to another embodiment. The data unit **200** conforms to the IEEE 802.11b Standard, and is modulated by direct sequence spread spectrum (DSSS) or complementary code keying (CCK), in various embodiments. The data unit **200** includes a synchronization (SYNC) field **202** that allows a receiver to detect the presence of the data unit **200** and begin synchronizing with the incoming signal. The data unit **200** also includes a start frame delimiter (SFD) field **204** that signals the beginning of a frame. SYNC field **202** and SFD field **204** form the preamble portion of the data unit **200**. The data unit **200** also includes a header portion containing a signal field **206**, a service field **808**, a length field **210**, and a cyclic check redundancy check (CRC) field **212**. The data unit **200** also includes a PHY service data unit (PSDU) **214**, i.e., the data portion.

In various embodiments and/or scenarios, data units that conform to a long range communication protocol (e.g., the IEEE 802.11af or 802.11ah Standard) are formatted at least substantially the same as defined by the IEEE 802.11a Standard, the 802.11n Standard (mixed mode or Greenfield), or the 802.11ac Standard, as described and shown above in connection with FIGS. **2-5**, but are transmitted at a lower frequency (e.g., sub-1 GHz) and using a slower clock rate. In some such embodiments, a transmitting device (e.g., the AP **14**) down-clocks by a factor of N the clock rate used for generating the short range data units, to a lower clock rate to be used for generating the long range data units. The long range data unit is therefore generally transmitted over a longer time, and optionally occupies a smaller bandwidth, than the corresponding short range data unit. The down-clocking factor N is different according to different embodiments and/or scenarios. In one embodiment, the down-clocking factor N is equal to 10. In other embodiments, other suitable down-clocking factor (N) values are utilized, and transmission times and bandwidths of long range data units are scaled accordingly. In some embodiments, the down-clocking factor N is a power of two (e.g., N=8, 16, 32, etc.).

Examples of long range data units generated by down-clocking are described in U.S. patent application Ser. No. 13/359,336, filed Jan. 26, 2012, which is hereby incorporated by reference herein. In some embodiments, and also as described in U.S. patent application Ser. No. 13/359,336, a long range communication protocol defines both "regular" mode data units that are down-clocked by a value N_1 and "extended range" data units that are down-clocked by a value N_2, where $N_2 > N_1$. Thus, in some embodiments, a device (e.g., the AP **14** and/or a client station **25**) selectively transmits a long range data unit at a first down-clocked rate or at a second, further down-clocked rate, depending on whether the device is in regular mode or extended range mode.

Due to the use of multiple clock rates to generate coexisting data units (e.g., short range and long range data units, and/or regular long range and extended long range data units) in a particular region, it is helpful if a communication device (e.g., the AP **14** and/or a client station **25**) receiving a data unit can determine or auto-detect the clock rate used to generate the data unit. As described in embodiments below, a first preamble portion of a data unit permits a receiving device to use a corresponding technique to auto-detect the clock rate of the data unit (e.g., to auto-detect the clock rate of the OFDM-modulated portion of the data unit that follows the first preamble portion). In the subsequently described embodiments, the OFDM-modulated portion of the data unit for which a clock rate is being detected is referred to as the "OFDM portion". In some embodiments (e.g., in some embodiments where the first preamble portion includes an STF), however, the first preamble portion is also OFDM-modulated.

In a first group of example embodiments, comprising a first, second, and third example embodiment and corresponding to FIGS. **7-9**, an STF of the preamble of a data unit is designed to indicate the clock rate of the OFDM portion of the data unit. The STF is used for one or more of packet detection, initial synchronization, automatic gain control, etc., in various embodiments. The OFDM portion includes one or more

LTFs, which in various embodiments are used for one or more of channel estimation, fine synchronization, etc. The preamble designs of FIGS. **7-9** are utilized in data units transmitted and/or received over a communication channel by a communication device (e.g., the AP **14** and/or a client station **25** of FIG. **1**), in various embodiments or scenarios. Each of FIGS. **7-9** illustrates two example preambles, each reflecting a PHY mode that corresponds to a particular clock rate. In one embodiment, an AP (e.g., AP **14**) is capable of generating both example preambles (i.e., the AP supports multiple PHY modes corresponding to different clock rates), while each client station (e.g., each of client stations **25**) is only capable of generating one of the example preambles (i.e., each client station only supports a PHY mode corresponding to a single clock rate). In another embodiment, both the AP and one or more of the client stations are capable of generating both example preambles.

For ease of explanation, FIGS. **7-9** show preambles that include only a first portion having a single STF and a second portion having a single LTF. In other embodiments, however, different types and/or numbers of fields are included in the preamble. For example, in an embodiment, the preamble includes multiple LTFs following the STF. As another example, in an embodiment, additional, non-LTF fields of the preamble (e.g., one or more SIG fields used for signaling basic PHY parameters to the receiver) follow the LTF. In some embodiments, the preambles are the same as any one of the preambles discussed above in connection with FIGS. **2-5**, but with the first STF being designed as in one of the embodiments described below in connection with FIGS. **7-9**. For example, in various embodiments, L-STF **102** of FIG. **2**, L-STF **122** of FIG. **3**, HT-GF-STF **142** of FIG. **4**, or L-STF **172** of FIG. **5** is designed according to an embodiment described below. Moreover, while FIGS. **7-9** each show preambles corresponding to only two possible clock rates, one of ordinary skill in the art will understand that the preamble designs and auto-detection techniques described below can be extended to systems including three or more coexisting PHY modes with different clock rates.

In the first example embodiment (discussed with respect to FIG. **7**), an STF of the preamble is down-clocked using the same down-clocking ratio as a subsequent OFDM portion of the data unit. Referring to FIG. **7**, a first preamble **300** is included in data units that have an OFDM portion clocked at a first clock rate (e.g., the normal clock rate of an IEEE 802.11a, 802.11n, or 802.11ac data unit, in an embodiment). The preamble **300** includes a first preamble portion **310** and a second preamble portion **314**. The first preamble portion **310** is clocked at a first clock rate and includes J repeating STF sequences **318-1** through **318-J**. The second preamble portion **314** includes at least a first long training field (LTF1) **324**, and is included in the OFDM portion of the data unit. In some embodiments, the OFDM portion of the data unit also includes a data portion (not shown in FIG. **7**).

A second preamble **330** is included in data units that have an OFDM portion clocked at a second clock rate lower than the first clock rate. In the example embodiment of FIG. **7**, the OFDM portion of a data unit with preamble **330** is clocked at a rate equal to ¼ the clock rate of the OFDM portion of the data unit with preamble **300** (e.g., generated by down-clocking from the first clock rate using N=4, in an embodiment). In other embodiments, the second clock rate differs from the first clock rate by a different ratio (e.g., a down-clocking ratio of N=8, 10, 16, etc. is used, in various embodiments). Similar to the preamble **300**, the preamble **330** includes a first preamble portion **340** and a second preamble portion **344**, with the first preamble portion **340** including J repeating STF sequences **348-1** through **348-J**. Also similar to the preamble **300**, the second preamble portion **344** includes at least a first long training field (LTF1) **354**, and is included in the OFDM portion of the data unit. Unlike the first preamble portion **310** of preamble **300**, however, the first preamble portion **340** of preamble **330** is clocked at the lower, second clock rate.

Because the STF sequences **348** are generated using a clock rate four times slower than the clock rate used to generate STF sequences **318**, and because the first preamble portion **310** and the first preamble portion **340** include the same number (J) of repeating STF sequences, the first preamble portion **340** of preamble **330** is four times longer in duration than the first preamble portion **310** of preamble **300**. A communication device receiving data units having preamble **300** and data units having preamble **330** can therefore take advantage of the length between the start of the first preamble portion and the end of the first preamble portion (i.e., in the embodiment of FIG. **7**, between the start of the first preamble portion and the STF/LTF boundary) to determine the clock rate of the OFDM portion before demodulating OFDM symbols within the OFDM portion. To this end, and as shown in FIG. **7**, a receiver performs autocorrelations on each received data unit. In one embodiment, a first autocorrelation is performed using a repetition period (time interval) corresponding to a first potential clock rate, and a second autocorrelation is performed using a repetition period corresponding to a second potential clock rate. In the example embodiment of FIG. **7**, the first autocorrelation utilizes a 0.8 μs interval corresponding to the 0.8 μs length of the STF sequences **318** clocked at the first clock rate, and the second autocorrelation utilizes a 3.2 μs interval corresponding to the 3.2 μs length of the STF sequences **348** clocked at the second clock rate. The first and the second autocorrelation are simultaneously performed by parallel carrier sense circuits and/or software modules of a PHY unit such as PHY unit **20** or PHY unit **29** of FIG. **1**, in an embodiment.

As shown in FIG. **7**, the first autocorrelation outputs a first carrier sense signal **380**, and the second autocorrelation outputs a second carrier sense signal **384**. In some embodiments, the pulse length of the first carrier sense signal **380** corresponds to an estimation of a length of time between sensing a carrier (depicted as the event CS **386**) and detecting a transition from the first preamble portion **310** to the second preamble portion **314** (depicted as the event "STF/LTF Boundary" **388**). Similarly, in some embodiments, the pulse length of the second carrier sense signal **384** corresponds to an estimation of a length of time between sensing a carrier (depicted as the event CS **390**) and detecting a transition from the first preamble portion **340** to the second preamble portion **344** (depicted as the event "STF/LTF Boundary" **392**).

In some embodiments, the carrier sense signal **380** and/or the carrier sense signal **384** is/are compared to a suitable predetermined threshold, and is/are determined to be "high" when meeting the threshold. In some embodiments, detecting CS **386** or CS **390** includes determining that such a threshold is met. Moreover, in some embodiments, a transition from the first preamble portion to the second preamble portion is detected when an autocorrelation goes below such a threshold (or below a different, second threshold) after having been "high" for a time period. In some embodiments, detecting STF/LTF Boundary **388** or STF/LTF Boundary **392** includes detecting such a transition. Although FIG. **7** represents the first carrier sense signal **380** and the second carrier sense signal **384** as continuous pulses, the term "pulse" as used herein includes both continuous and non-continuous pulses (e.g., signals that are not necessarily "high" or "low" for the

entire pulse length, but meet some suitable predetermined criteria for the entire pulse length).

In some embodiments, a receiver detects the clock rate of a received data unit by determining which carrier sense signal indicates a strong autocorrelation when operating on the STF portion. For example, if the second carrier sense signal **384** rises but the first carrier sense signal **380** does not rise, the receiver determines that the received STF sequences (and therefore, the corresponding OFDM portion of the data unit) are clocked at the lower, second clock rate, in an embodiment. Conversely, in this embodiment, if the first carrier sense signal **380** rises but the second carrier sense signal **384** does not rise, the receiver determines that the received STF sequences (and therefore, the corresponding OFDM portion of the data unit) are clocked at the higher, first clock rate. In other words, as an example, if the second carrier sense signal **384** meets suitable detection criteria but the first carrier sense signal **380** does not meet suitable detection criteria, the receiver determines that the received STF sequences (and therefore, the corresponding OFDM portion of the data unit) are clocked at the lower, second clock rate, in an embodiment. Conversely, in this embodiment, if the first carrier sense signal **380** meets suitable detection criteria but the second carrier sense signal **384** does not meet suitable detection criteria, the receiver determines that the received STF sequences (and therefore, the corresponding OFDM portion of the data unit) are clocked at the higher, first clock rate.

In some instances, however, an STF sequence clocked at a higher rate can trigger carrier sensing corresponding to a lower clocked rate. For example, a received data unit with STF sequences **318** (clocked at the higher, first clocked rate) can cause both the first carrier sense signal **380** and the second carrier sense signal **384** to indicate detection of a carrier, in some embodiments and/or scenarios. In this situation, the receiver determines the clock rate of the OFDM portion of the data unit based on a pulse length of at least one of the carrier sense signals **380**, **384**, in an embodiment. For example, in one embodiment where each STF includes J=10 sequences (e.g., the first preamble portion **310** of FIG. **7** is 8.0 μs long and the second preamble portion **340** of FIG. **7** is 32 μs long), the receiver determines that the clock rate of the OFDM portion is the first clock rate when the carrier sense signals **380**, **384** indicate an 8.0 μs length between a start of carrier detection and the STF/LTF boundary, and determines that the clock rate of the OFDM portion is the second clock rate when the carrier sense signals **380**, **384** indicate a 32 μs length between a start of carrier detection and the STF/LTF boundary. Various other embodiments use other algorithms. As one example, where J=10, a receiver determines that the clock rate is the first clock rate when the STF/LTF boundary occurs within 10 μs of the start of carrier detection, and determines that the clock rate is the second clock rate when the STF/LTF boundary occurs more than 10 μs after the start of carrier detection, in an embodiment. In some embodiments and scenarios where both the carrier sense signal **380** and the carrier sense signal **384** indicate detection of a carrier, the receiver determines the clock rate by observing the pulse length of only one of the carrier sense signals. In other embodiments, the respective pulse lengths of both carrier sense signals are observed.

Because both carrier sense signals **380**, **384** may initially indicate a carrier sense, a receiver using the example auto-detection technique of FIG. **7** may not be able to determine the clock rate of a received data unit until a time well after the beginning of the first preamble portion, and therefore may not have enough time to dynamically adjust the receiver clock rate based on the detected clock rate. Accordingly, a receiver employing the auto-detection technique of FIG. **7** operates at a clock rate corresponding to the faster of the first and the second clock rates, in an embodiment.

In the second example embodiment (discussed with respect to FIG. **8**), an STF of the preamble includes repeated STF sequences that are generated using a constant clock rate, regardless of the clock rate of the subsequent OFDM portion of the data unit. The STF, however, provides an indication of the clock rate of the OFDM portion by including more or fewer repetitions of the STF sequence. Referring to FIG. **8**, a first preamble **400** is included in data units that have an OFDM portion clocked at a first clock rate (e.g., the normal clock rate of an IEEE 802.11a, 802.11n, or 802.11 ac data unit). The preamble **400** includes a first preamble portion **410** and a second preamble portion **414**. The first preamble portion **410** includes J repeating STF sequences **418-1** through **418-J**. The second preamble portion **414** includes at least a first long training field (LTF1) **424**, and is included in the OFDM portion of the data unit. In some embodiments, the OFDM portion of the data unit also includes a data portion (not shown in FIG. **8**).

A second preamble **430** is included in data units that have an OFDM portion clocked at a second clock rate lower than the first clock rate. For example, in an embodiment, the OFDM portion of a data unit with preamble **430** is clocked at a rate equal to ¼ the clock rate of the OFDM portion of the data unit with preamble **400** (e.g., generated by down-clocking from the first clock rate using N=4, in an embodiment). In other embodiments, the second clock rate differs from the first clock rate by a different ratio (e.g., a down-clocking ratio of N=8, 10, 16, etc. is used, in various embodiments). Similar to the preamble **400**, the preamble **430** includes a first preamble portion **440** and a second preamble portion **444**, with the second preamble portion **444** including at least a first long training field (LTF1) **454** and being included in the OFDM portion of the data unit. Moreover, in an embodiment, the first preamble portion **440** of preamble **430** is clocked at the same clock rate as the first preamble portion **410** of preamble **400** (e.g., both being clocked at the first clock rate, or both being clocked at the second clock rate, according to various embodiments). Unlike the first preamble portion **410**, however, the first preamble portion **440** includes K repeating STF sequences **448-1** through **448-K**, where K is greater than J. In some embodiments, the ratio K/J is equal to the ratio of the first clock rate to the second clock rate. For example, in one embodiment where the first clock rate is four times greater than the second clock rate, the ratio K/J=4. In other embodiments, the ratio K/J is different than the ratio of the first clock rate to the second clock rate.

Because the first preamble portion **440** of preamble **430** includes more STF sequences than the first preamble portion **410** of preamble **400**, the first preamble portion **440** is longer than the first preamble portion **410**. A communication device receiving data units having preamble **400** and data units having preamble **430** can therefore take advantage of the length between the start of the first preamble portion and the end of the first preamble portion (i.e., in the embodiment of FIG. **8**, between the start of the first preamble portion and the STF/LTF boundary) to determine the clock rate of the OFDM portion before demodulating OFDM symbols within the OFDM portion. To this end, and as shown in FIG. **8**, a receiver performs an autocorrelation on each received data unit. Unlike the first example embodiment of FIG. **7**, only one autocorrelation is performed on a received data unit, in an embodiment. In one embodiment, the autocorrelation is performed using a repetition period (time interval) corresponding to the clock rate used to generate both first preamble

portion **410** and first preamble portion **440**. In the example embodiment of FIG. **8**, the autocorrelation utilizes a 3.2 μs interval corresponding to the 3.2 μs length of the STF sequences **418** and the STF sequences **448**.

Whereas FIG. **7** illustrates alternative autocorrelation outputs that correspond to outputs of different (e.g., parallel) carrier sense circuits and/or software modules, both autocorrelation outputs shown in FIG. **8** represent alternative outputs of the same carrier sense circuit and/or software module. A first carrier sense signal **480** is output by the autocorrelation when a data unit with preamble **400** is received, and a second carrier sense signal **484** is output by the autocorrelation when a data unit with preamble **430** is received. In some embodiments, the pulse length of the first carrier sense signal **480** corresponds to an estimation of a length of time between sensing a carrier (depicted as the event CS **486**) and detecting a transition from the first preamble portion **410** to the second preamble portion **414** (depicted as the event "STF/LTF Boundary" **488**). Similarly, in some embodiments, the pulse length of the second carrier sense signal **484** corresponds to an estimation of a length of time between sensing a carrier (depicted as the event CS **490**) and detecting a transition from the first preamble portion **440** to the second preamble portion **444** (depicted as the event "STF/LTF Boundary" **492**).

In some embodiments, a receiver determines the clock rate of the OFDM portion of a received data unit based on a pulse length of the carrier sense signal. For example, in one embodiment where J=4 and K=16 (e.g., the first preamble portion **410** in the example embodiment of FIG. **8** is 12.8 μs long and the second preamble portion **440** of FIG. **8** is 51.2 μs long), the receiver determines that the clock rate of the OFDM portion is the first clock rate when the carrier sense signal indicates a 12.8 μs length between a carrier sense and the STF/LTF boundary, and determines that the clock rate of the OFDM portion is the second clock rate when the carrier sense signal indicates a 51.2 μs length between a carrier sense and the STF/LTF boundary. Various other embodiments use other algorithms. As one example, again where J=4 and K=16, a receiver determines that the clock rate is the first clock rate when the STF/LTF boundary occurs within 20 μs of the carrier sense, and determines that the clock rate is the second clock rate when the STF/LTF boundary occurs more than 20 μs after the carrier sense, in an embodiment. In other embodiments, different suitable values of J and K are utilized.

As with the example auto-detection technique of FIG. **7**, the example auto-detection technique of FIG. **8** may not provide enough time to dynamically adjust the receiver clock rate based on the detected clock rate. Accordingly, a receiver employing the auto-detection technique of FIG. **8** operates at a clock rate corresponding to the faster of the first and the second clock rates, in an embodiment.

In the third example embodiment (discussed with respect to FIG. **9**), an STF of the preamble includes repeated STF sequences that are generated using a constant clock rate, regardless of the clock rate of the subsequent OFDM portion of the data unit. A repeated STF sequence, however, is augmented by a cover code that provides an indication of the clock rate of the OFDM portion. In one embodiment, this preamble design is combined with the preamble design of FIG. **8**, where the clock rate of the OFDM portion is additionally indicated by the number of repetitions of the STF sequence. FIG. **9** illustrates an example preamble design and corresponding auto-detection technique for an embodiment where both a cover code and the number of STF sequences are used to indicate the clock rate of the OFDM portion. Referring to FIG. **9**, a first preamble **500** is included in data units that have an OFDM portion clocked at a first clock rate (e.g., the normal clock rate of an IEEE 802.11a, 802.11n, or 802.11 ac data unit, in various embodiments). The preamble **500** includes a first preamble portion **510** and a second preamble portion **514**. The first preamble portion **510** includes J repeating STF sequences **518-1** through **518**-J that are augmented by a first cover code. The first cover code corresponds to the first clock rate (i.e., is used to indicate to a receiving device that the first clock rate is used for the OFDM portion of the data unit). The second preamble portion **514** includes at least a first long training field (LTF1) **524**, and is included in the OFDM portion of the data unit. In some embodiments, the OFDM portion of the data unit also includes a data portion (not shown in FIG. **9**).

A second preamble **530** is included in data units that have an OFDM portion clocked at a second clock rate lower than the first clock rate. For example, in an embodiment, the OFDM portion of a data unit with preamble **530** is clocked at a rate equal to ¼ the clock rate of the OFDM portion of the data unit with preamble **500** (e.g., by down-clocking from the first clock rate using N=4, in an embodiment). In other embodiments, the second clock rate differs from the first clock rate by a different ratio (e.g., a down-clocking ratio of N=8, 10, 16, etc. is used, in various embodiments). Similar to the preamble **500**, the preamble **530** includes a first preamble portion **540** and a second preamble portion **544**, with the second preamble portion **544** including at least a first long training field (LTF1) **554** and being included in the OFDM portion of the data unit. Moreover, in an embodiment, the first preamble portion **540** of preamble **530** is clocked at the same clock rate as the first preamble portion **510** of preamble **500** (e.g., both being clocked at the first clock rate, or both being clocked at the second clock rate, according to various embodiments). Unlike the first preamble portion **510**, however, the first preamble portion **540** includes STF sequences **548** that are augmented by a second cover code different than the first cover code. The second cover code corresponds to the lower, second clock rate (i.e., is used to indicate to a receiving device that the OFDM portion of the data unit is clocked at the second clock rate). In an embodiment, the first cover code, used in preamble **500**, is a series of only positive ones (i.e., [1 1 1 1 . . .]), while the second cover code, used in preamble **530**, is a series of alternating positive and negative ones (i.e., [1 −1 1 −1 . . .]).

As seen in FIG. **9**, the first preamble portion **540** of preamble **530** includes K repeating STF sequences **548-1** through **548**-K. In embodiments such as the example embodiment illustrated in FIG. **9**, where the clock rate of the OFDM portion is additionally indicated by the number of STF sequences, K is greater than J. In some of these embodiments, the ratio K/J is equal to the ratio of the first clock rate to the second clock rate. Alternatively, in some embodiments where the clock rate of the OFDM portion is not indicated by the number of STF sequences, K is equal to J.

Because the cover code of the first preamble section is not known a priori for a particular received data unit, a receiver processes the first preamble portion of the received data unit in two parallel paths, in an embodiment. In a first path the receiver attempts to remove or undo the first cover code, and in a second path the receiver attempts to remove or undo the second cover code, in an embodiment. A first autocorrelation of at least the first preamble portion (as processed) follows the cover code processing in the first path, and a second, parallel autocorrelation of at least the first preamble portion (as processed) follows the cover code processing in the second path, in an embodiment. For example, in one embodiment where the first cover code is a series of positive ones and the second cover code is a series of alternating positive ones and negative

ones, the first autocorrelation is a conventional autocorrelation, but the samples of one of the two windows of the second autocorrelation are multiplied by negative one.

As shown in FIG. **9**, the first autocorrelation outputs a first carrier sense signal **580**, and the second autocorrelation outputs a second carrier sense signal **584**. In some embodiments, a receiver detects the clock rate of a received data unit by determining which carrier sense signal indicates a strong autocorrelation when operating on the STF portion. For example, if the second carrier sense signal **584** rises (i.e., carrier sense **586** occurs) but the first carrier sense signal **580** does not rise (i.e., carrier sense **590** does not occur), the receiver determines that the OFDM portion of the data unit is clocked at the lower, second clock rate, in an embodiment. Conversely, in this embodiment, if the first carrier sense signal **580** rises but the second carrier sense signal **584** does not rise, the receiver determines that the OFDM portion of the data unit is clocked at the higher, first clock rate. In some embodiments where the clock rate is additionally indicated by the number of STF sequences (i.e., where K>J), the receiver also determines, or confirms, the clock rate based on the pulse length of carrier sense signal **580** and/or carrier sense signal **584** (e.g., the position of the STF/LTF boundary **592** or the STF/LTF boundary **596**), similar to the auto-detection method of FIG. **8**. In other words, as an example, if the second carrier sense signal **584** meets suitable detection criteria but the first carrier sense signal **580** does not meet suitable detection criteria, the receiver determines that the corresponding OFDM portion of the data unit is clocked at the lower, second clock rate, in an embodiment. Conversely, in this embodiment, if the first carrier sense signal **580** meets suitable detection criteria but the second carrier sense signal **584** does not meet suitable detection criteria, the receiver determines that the OFDM portion of the data unit is clocked at the higher, first clock rate.

A receiver using the example auto-detection technique of FIG. **9** is generally able to quickly determine the clock rate of a received data unit (e.g., based on the carrier sense **586** or carrier sense **590**). Thus, in an embodiment, the receiving device is configured to dynamically adjust the receiver clock rate to correspond to the determined clock rate of the OFDM portion, which can save power in the receiving device. In some of these embodiments, the receiving device is configured to dynamically adjust the receiver clock rate in response to the occurrence of carrier sense **586** or carrier sense **590**, depending on whether a data unit with an OFDM portion clocked at the first clock rate or the second clock rate is received. In an embodiment, the receiving device is configured to dynamically adjust the receiver clock rate before processing (e.g., demodulating) any part of the OFDM portion of the data unit.

In a second group of example embodiments, comprising fourth, fifth, and sixth example embodiments, and corresponding to FIGS. **10-12**, an SC "extra preamble" portion serves as a first preamble portion of a long range data unit, where the extra preamble portion is designed to reflect the clock rate of the OFDM portion of the data unit. In some embodiments, formats of the data units of FIGS. **10-12** are similar to a short range data unit, with the exception of the extra preamble portion. The extra preamble portion includes a SYNC field (e.g., similar to a SYNC field according to the IEEE 802.11b Standard) and, in some embodiments, an SFD field (e.g., similar to an SFD field according to the IEEE 802.11b Standard). In these example embodiments, the SYNC field and/or the SFD field is/are designed to reflect the clock rate of the OFDM portion of the data unit. In some embodiments where a data unit is generated for transmission via multiple, aggregated 20 MHz channels (e.g., via a 40 MHz, 80 MHz, 160 MHz, etc. channel), the extra preamble portion is repeated in each 20 MHz sub-band.

The extra preamble portion is sampled or clocked at a lower rate than the OFDM portion of the data unit, in some embodiments. For example, in one embodiment, the extra preamble portion is down-clocked from the IEEE 802.11b rate of 11 MHz by a down-clock ratio N equal to a down-clocking ratio used for the OFDM portion of the data unit. As another example, in another embodiment, the extra preamble portion is sampled or clocked with approximately ⅔ the clock rate of the regular (not down-clocked) OFDM portion. In some embodiments where the extra preamble portion is sampled or clocked at a different rate than the OFDM portion, one or more particular requirements with respect to the SC/OFDM boundary between the extra preamble portion and the OFDM portion are satisfied. For example, the SC/OFDM boundary requirement defined in the IEEE 802.11g Standard is satisfied, in an embodiment.

The preamble designs of FIGS. **10-12** are utilized in data units transmitted and/or received over a communication channel by a communication device (e.g., the AP **14** and/or a client station **25** of FIG. **1**), in various embodiments or scenarios. Each of FIGS. **10-12** illustrates two example preambles, each reflecting a PHY mode that corresponds to a particular clock rate of the OFDM portion. In one embodiment, an AP (e.g., AP **14**) is capable of generating both example preambles (i.e., the AP supports multiple PHY modes corresponding to different clock rates), while each client station (e.g., each of client stations **25**) is only capable of generating one of the example preambles (i.e., each client station only supports a PHY mode corresponding to a single clock rate). In another embodiment, both the AP and one or more of the client stations are capable of generating both example preambles.

In some embodiments, the preambles of FIGS. **10-12** include different types and/or numbers of fields than shown. For example, in an embodiment, additional fields are included between the extra preamble portion and the STF (or, in embodiments without an STF, between the extra preamble portion and an LTF). In some embodiments, the preambles are the same as any one of the preambles discussed above in connection with FIGS. **2-5**, but with one of the extra preamble portions described below in connection with FIGS. **10-12** being added at the beginning of the preamble. For example, in various embodiments, the extra preamble portion is added before L-STF **102** of FIG. **2**, L-STF **122** of FIG. **3**, HT-GF-STF **142** of FIG. **4**, or L-STF **172** of FIG. **5**. Moreover, while FIGS. **10-12** each show preambles corresponding to only two possible clock rates, one of ordinary skill in the art will understand that the preamble designs and auto-detection techniques described below can be extended to systems including three or more coexisting PHY modes with different clock rates.

In the fourth example embodiment (discussed with respect to FIG. **10**), the preamble includes a SYNC field that is generated using a constant clock rate, regardless of the clock rate of the OFDM portion of the corresponding data unit. The SYNC field, however, has a particular length based on the clock rate of the OFDM portion, allowing a receiver to differentiate between clock rates based on the SYNC field. Referring to FIG. **10**, a first preamble **600** is included in data units that have an OFDM portion clocked at a first clock rate (e.g., the normal clock rate of an IEEE 802.11a, 802.11n, or 802.11ac data unit, in various embodiments). The preamble **600** includes a first preamble portion **610** (i.e., the "extra preamble" portion) and a second preamble portion **612**. The

first preamble portion **610** includes a SYNC field **614** and an SFD field **616**. In an embodiment, the first preamble portion includes a number of repetitions of a Barker code. The second preamble portion **612** is included in the OFDM portion of the data unit, and includes an STF **620** and a preamble portion **622** with one or more LTFs and a SIG field. In some embodiments, the OFDM portion of the data unit also includes a data portion (not shown in FIG. **10**). In an alternative embodiment, the preamble **600** does not include SFD field **616**. In another alternative embodiment, SFD field **616** is included in preamble **600** but STF **620** is not included.

A second preamble **630** is included in data units that have an OFDM portion clocked at a second clock rate lower than the first clock rate. For example, in an embodiment, the OFDM portion of a data unit with preamble **630** is clocked at a rate equal to ¼ the clock rate of the OFDM portion of the data unit with preamble **600** (e.g., by down-clocking from the first clock rate using N=4, in an embodiment). In other embodiments, the second clock rate differs from the first clock rate by a different suitable ratio (e.g., a down-clocking ratio of N=8, 10, 16, etc. is used, in various embodiments). Similar to the preamble **600**, the preamble **630** includes a first preamble portion **640** and a second preamble portion **642**, with the first preamble portion **640** including a SYNC field **644** and an SFD field **646**. Also similar to the preamble **600**, the second preamble portion **642** is included in the OFDM portion, and includes an STF **650** and a preamble portion **652** with one or more LTFs and a SIG field. Further, in an embodiment, the first preamble portion **640** of preamble **630** is clocked at the same clock rate as the first preamble portion **610** of preamble **600** (e.g., both being clocked at the first clock rate, or both being clocked at the second clock rate, according to various embodiments). SYNC field **644**, however, is longer than SYNC field **614** of preamble **600**. In one embodiment, SYNC field **644** includes a number of repetitions of a Barker code that is greater than a number of repetitions of the same Barker code in SYNC field **614**. For example, SYNC field **644** includes a number of repetitions of a Barker code that is N times greater than the number of repetitions of the same Barker code in SYNC field **614** when the first clock rate is N times greater than the second clock rate. In some embodiments, the SFD field is also utilized to differentiate between the first and second clock rates. In these embodiments, SFD field **646** of preamble **630** is different than SFD field **616** of preamble **600**.

In an embodiment, a communication device receiving data units having preamble **600** and data units having preamble **630** takes advantage of the different SYNC fields (and, in some embodiments, the different SFD fields) of preamble **600** and preamble **630** to determine the clock rate of the OFDM portion before demodulating OFDM symbols in the OFDM portion. In some embodiments, the receiver performs an auto-correlation to detect which SYNC field (and therefore, which OFDM portion clock rate) is used in the received packet.

In the fifth example embodiment (discussed with respect to FIG. **11**), the preamble again includes a SYNC field that is generated using a constant clock rate, regardless of the clock rate of the OFDM portion of the corresponding data unit. The SYNC field, however, includes a particular repeated sequence based on the clock rate of the OFDM portion, allowing a receiver to differentiate between clock rates based on the SYNC field. Referring to FIG. **11**, a first preamble **700** is included in data units that have an OFDM portion clocked at a first clock rate (e.g., the normal clock rate of an IEEE 802.11a, 802.11n, or 802.11 ac data unit, in various embodiments). The preamble **700** includes a first preamble portion **710** (i.e., the "extra preamble" portion) and a second preamble portion **712**. The first preamble portion **710** includes a SYNC field **714** and a start frame delimiter field SFD field **716**. SYNC field **714** includes a first repeated sequence (Ga). In an embodiment, the first repeated sequence is a first Golay sequence. The second preamble portion **712** is included in the OFDM portion of the data unit, and includes an STF **720** and a preamble portion **722** with one or more LTFs and a SIG field. In some embodiments, the OFDM portion of the data unit also includes a data portion (not shown in FIG. **11**). In an alternative embodiment, the preamble **700** does not include SFD field **716**. In another alternative embodiment, SFD field **716** is included in preamble **700**, but STF **720** is not included.

A second preamble **730** is included in data units that have an OFDM portion clocked at a second clock rate lower than the first clock rate. For example, in an embodiment, the OFDM portion of a data unit with preamble **730** is clocked at a rate equal to ¼ the clock rate of the OFDM portion of the data unit with preamble **700** (e.g., by down-clocking from the first clock rate using N=4, in an embodiment). In other embodiments, the second clock rate differs from the first clock rate by a different suitable ratio (e.g., a down-clocking ratio of N=8, 10, 16, etc. is used, in various embodiments). Similar to the preamble **700**, the preamble **730** includes a first preamble portion **740** and a second preamble portion **742**, with the first preamble portion **740** including a SYNC field **744**. Also similar to the preamble **700**, the second preamble portion **742** is included in the OFDM portion, and includes an STF **750** and a preamble portion **752** with one or more LTFs and a SIG field. Further, in an embodiment, the first preamble portion **740** of preamble **730** is clocked at the same clock rate as the first preamble portion **710** of preamble **700** (e.g., both being clocked at the first clock rate, or both being clocked at the second clock rate, according to various embodiments). SYNC field **744**, however, includes a second repeated sequence (Gb) different than the first repeated sequence Ga. In some embodiments, the second repeated sequence is a second Golay sequence complementary to the first Golay sequence. In some embodiments, the sequences Ga and Gb are suitable complementary sequences other than Golay sequences. In an embodiment, complementary sequences Ga and Gb are selected so that the sum of corresponding out-of-phase aperiodic autocorrelation coefficients of the sequences Ga and Gb is zero. In some embodiments, complementary sequences Ga and Gb have a zero or almost-zero periodic cross-correlation. In another aspect, sequences Ga and Gb have aperiodic cross-correlation with a narrow main lobe and low-level side lobes, or aperiodic auto-correlation with a narrow main lobe and low-level side lobes.

Generally, the two complementary sequences of SYNC field **714** and SYNC field **744** have correlation properties suitable for detection at a receiving device. In embodiments where the sequences are Golay sequences, Golay sequences of length **16**, **32**, **64**, **128**, or any other suitable length are utilized for the complementary sequences. In an embodiment, pi/2 chip-level rotation is applied to the Golay code sequences in the same manner as defined in the IEEE802.11ad Standard.

The preamble **730** also includes a start frame delimiter field SFD field **746**, which in some embodiments is different than SFD field **716**. In an alternative embodiment, where preamble **700** does not include SFD field **716**, the preamble **730** does not include SFD field **746**. In another alternative embodiment, where preamble **700** includes SFD field **716** but not STF **720**, preamble **730** includes SFD field **746** but not STF **750**. In an embodiment, both SFD field **716** and SFD field **746** each include one or more of the sequences (e.g., Golay sequences) repeated in the SYNC field, but augmented by a sign flip (i.e., reversed polarity, e.g., –Ga or –Gb). In another

embodiment, both SFD field **716** and SFD field **746** include a sequence that is complementary to the repeated sequence of the SYNC field. For example, SFD field **746** of preamble **730** includes a first Golay sequence utilized in SYNC field **714** of preamble **700**, and SFD field **716** of preamble **700** includes a second Golay sequence utilized in SYNC field **744** of preamble **730**, in an embodiment.

In an embodiment, a communication device receiving data units having preamble **700** and data units having preamble **730** takes advantage of the different SYNC fields (and, in some embodiments, the different SFD fields) of preamble **700** and preamble **730** to determine the clock rate of the OFDM portion before demodulating OFDM symbols in the OFDM portion. In some embodiments, the receiver performs parallel cross-correlations, each of which correlates the received sequences with one of the possible SYNC field sequences, and compares the outputs of the cross-correlations to determine which SYNC field (and, therefore, which OFDM portion clock rate) is used in the received packet.

In the sixth example embodiment (discussed with respect to FIG. **12**), the preamble includes a SYNC field that does not change based on the OFDM portion clock rate. However, the preamble includes a different SFD field for each different clock rate. Referring to FIG. **12**, a first preamble **800** is included in data units that have an OFDM portion clocked at a first clock rate (e.g., the normal clock rate of an IEEE 802.11a, 802.11n, or 802.11ac data unit, in various embodiments). The preamble **800** includes a first preamble portion **810** (i.e., the "extra preamble" portion) and a second preamble portion **812**. The first preamble portion **810** includes a SYNC field **814** and a first start frame delimiter (SFD1) field **816**. The second preamble portion **812** is included in the OFDM portion of the data unit, and includes an STF **820** and a preamble portion **822** with one or more LTFs and a SIG field. In some embodiments, the OFDM portion of the data unit also includes a data portion (not shown in FIG. **12**). In an alternative embodiment, the preamble **800** does not include STF **820**.

A second preamble **830** is included in data units that have an OFDM portion clocked at a second clock rate lower than the first clock rate. For example, in an embodiment, the OFDM portion of a data unit with preamble **830** is clocked at a rate equal to ¼ the clock rate of the OFDM portion of the data unit with preamble **800** (e.g., by down-clocking from the first clock rate using N=4, in an embodiment). In other embodiments, the second clock rate differs from the first clock rate by a different suitable ratio (e.g., a down-clocking ratio of N=8, 10, 16, etc. is used, in various embodiments). Similar to the preamble **800**, the preamble **830** includes a first preamble portion **840** and a second preamble portion **842**, with the first preamble portion **840** including a SYNC field **844**. Also similar to the preamble **800**, the second preamble portion **842** is included in the OFDM portion, and includes an STF **850** and a preamble portion **852** with one or more LTFs and a SIG field. Further, in an embodiment, the first preamble portion **840** of preamble **830** is clocked at the same clock rate as the first preamble portion **810** of preamble **800** (e.g., both being clocked at the first clock rate, or both being clocked at the second clock rate, according to various embodiments). The first preamble portion **840**, however, includes a second start frame delimiter (SFD2) field **846** that is different than SFD1 field **816**. For example, in one embodiment, SFD1 field **816** includes one or more sequences that are repeated in SYNC field **814** but with a sign flip, while SFD2 field **846** includes the one or more sequences without the sign flip. As another example, in one embodiment, SFD1 field **816** includes one or more repetitions of a sequence that is different than a sequence repeated one or more times in SFD2 field **846**.

In an embodiment, a communication device receiving data units having preamble **800** and data units having preamble **830** takes advantage of the different SFD fields of preamble **800** and preamble **830** to determine the clock rate of the OFDM portion before demodulating OFDM symbols in the OFDM portion. In some embodiments where SFD1 field **816** and SFD2 field **846** include different sequences, or where SFD2 field **846** includes the same sequence as SFD1 field **816** but with a sign flip, a receiver performs parallel cross-correlations to detect which SFD (and, therefore, which OFDM portion) is used in the received packet.

FIG. **13** is a flow diagram of an example method **900** for generating a data unit according to the first, second, third, fourth, fifth, or sixth example preamble design (of which example embodiments are shown in FIGS. **7-12**, respectively), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **900** to generate a data unit for transmission over a communication channel.

At block **902**, a first preamble portion is generated based on a PHY mode. More specifically, the first preamble portion is generated based at least on whether the PHY mode is a first PHY mode or a second PHY mode. In an embodiment, the first and second PHY modes correspond to particular communication protocols or particular modes of a communication protocol. For example, in one embodiment, the first PHY mode corresponds to a short range communication protocol and the second PHY mode corresponds to a long range communication protocol. As another example, in an embodiment, the first PHY mode corresponds to a regular mode of a long range communication protocol and the second PHY mode corresponds to an extended range mode of the long range communication protocol. In some embodiments, the first preamble portion is generated also based on whether the PHY mode is one or more other possible PHY modes (e.g., a third PHY mode, a fourth PHY mode, etc.). For example, in an embodiment, the first PHY mode corresponds to a short range communication protocol, the second PHY mode corresponds to a regular mode of a long range communication protocol, and a third PHY mode corresponds to an extended range mode of the long range communication protocol.

In some embodiments, the first preamble portion is OFDM-modulated. For example, in an embodiment, the first preamble portion includes an OFDM-modulated STF. In other embodiments, the first preamble portion uses SC modulation. For example, in an embodiment, the first preamble portion includes an SC SYNC field. More specific examples of first preamble portions that are based on the PHY mode are described below in connection with FIGS. **15**, **17**, **19**, **21**, and **23**.

At block **904**, an OFDM portion is generated using a first clock rate or a second clock rate based on the PHY mode. More specifically, the OFDM portion is clocked at the first clock rate when the PHY mode is the first PHY mode, and is clocked at the second clock rate when the PHY mode is the second PHY mode. The second clock rate is lower than the first clock rate (e.g., in some embodiments, by an integer factor N). The OFDM portion follows the first preamble portion in the data unit being generated, and includes a second preamble portion that includes one or more LTFs. In some embodiments, the OFDM portion also includes a data portion of the data unit. In some embodiments, the OFDM portion is the same as a corresponding portion of a short range data unit

or long range data unit as described in connection with FIGS. **2-5**. In some of these embodiments, the design of the OFDM portion is based on the PHY mode.

Although FIG. **13** shows only blocks **902** and **904** in the method **900**, some embodiments include additional method elements. For example, in an embodiment, a third method element after block **904** includes transmitting via a communication channel (e.g., a wireless communication channel) a data unit that includes the generated first preamble portion and the generated OFDM portion. Moreover, although block **904** is shown later in the flow diagram of example method **900** than block **902**, block **904** occurs before, or simultaneously with, block **902** in other embodiments.

FIG. **14** is a flow diagram of an example method **910** for auto-detecting a clock rate of a data unit generated according to the first, second, third, fourth, fifth, or sixth example preamble design (of which example embodiments are shown in FIGS. **7-12**, respectively), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **910**.

At block **912**, a data unit is received via a communication channel. In an embodiment where the method **910** is implemented by an AP such as AP **14** of FIG. **1**, the data unit is received via an antenna such as one or more of antennas **24** of FIG. **1** and a PHY unit such as PHY unit **20** of FIG. **1**. In an embodiment where the method **910** is implemented by a client station such as client station **25-1** of FIG. **1**, the data unit is received via an antenna such as one or more of antennas **34** of FIG. **1** and a PHY unit such as PHY unit **29** of FIG. **1**. In an embodiment, the communication channel is a wireless communication channel.

The data unit received at block **912** includes a first preamble portion, and an OFDM portion that follows the first preamble portion. The OFDM portion of the data unit includes a second preamble portion including one or more LTFs. According to various embodiments, the received data unit is a data unit having the preamble design described in connection with any one of FIGS. **7-12**. Additionally or alternatively, according to various embodiments, the received data unit is a data unit generated according to the method of any one of FIG. **15**, **17**, **19**, **21**, or **23**, described below.

At block **914**, a clock rate of the OFDM portion of the data unit received at block **912** is auto-detected or determined based on the first preamble portion of the data unit. More specifically, it is determined whether the clock rate is a first clock rate corresponding to a first PHY mode or a lower, second clock rate corresponding to a second PHY mode, in an embodiment. In various embodiments, the PHY modes are similar to any of the PHY modes described in connection with block **902** of method **900** in FIG. **13**. More specific examples of how the clock rate of the OFDM portion is determined are described below in connection with FIGS. **16**, **18**, **20**, **22**, and **24**.

Although FIG. **14** shows only blocks **912** and **914** in the method **910**, some embodiments include additional method elements. Moreover, while the method **910** has been described with reference to determining a first or a second clock rate, some embodiments additionally determine (at block **914**) whether the clock rate is a third clock rate, a third or a fourth clock rate, etc.

FIG. **15** is a flow diagram of an example method **920** for generating a data unit according to the first example preamble design (of which an example embodiment is shown in FIG. **7**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **920** to generate a data unit for transmission over a communication channel.

At block **922**, it is determined whether a PHY mode of a communication device implementing the method **920** is a first PHY mode or a second PHY mode. In an embodiment, the first and second PHY modes correspond to particular communication protocols or particular modes of a communication protocol, such as described above in connection with block **902** of method **900** in FIG. **13**.

If it is determined at block **922** that the PHY mode is the first PHY mode, the flow proceeds to block **924**. At block **924**, a first preamble portion is generated using a first clock rate that corresponds to the first PHY mode. In various embodiments, the first preamble portion is OFDM-modulated (e.g., includes an OFDM-modulated STF, in an embodiment) or uses SC modulation (e.g., includes an SC SYNC field, in an embodiment).

At block **926**, an OFDM portion is generated using the first clock rate. The OFDM portion follows the first preamble portion in the data unit being generated, and includes a second preamble portion that includes one or more LTFs. In an embodiment, the OFDM portion also includes a data portion of a data unit. In some embodiments, the OFDM portion is the same as a corresponding portion of a short range data unit or long range data unit as described in connection with FIGS. **2-5**. In some of these embodiments, the design of the OFDM portion is based on the PHY mode determined at block **922**.

On the other hand, if it is determined at block **922** that the PHY mode is the second PHY mode, the flow proceeds to block **930**. At block **930**, a first preamble portion is generated using a second clock rate that corresponds to the second PHY mode. In some embodiments, the first preamble portion generated at block **930** is the same as or similar to the first preamble portion generated at block **924**, with the exception of the clock rate (and therefore length) of the first preamble portion. For example, in an embodiment, the first preamble portion generated at block **930** uses the same type of modulation (e.g., OFDM, SC, etc.), and includes the same repeating sequence and the same number of repetitions of the sequence, as the first preamble portion generated at block **924**. The second clock rate is lower than the first clock rate (e.g., in some embodiments, by an integer factor N).

At block **932**, an OFDM portion is generated using the second clock rate. The OFDM portion follows the first preamble portion in the data unit being generated, and includes a second preamble portion that includes one or more LTFs. In some embodiments, the OFDM portion generated at block **932** is the same as the OFDM portion generated at block **926**, with the exception of the clock rate (and therefore length) of the OFDM portion.

In some embodiments, the method **920** of FIG. **15** includes additional method elements not shown. For example, in an embodiment, after block **926** and after block **932**, an additional method element includes transmitting via a communication channel (e.g., a wireless communication channel) a data unit that includes both the generated first preamble portion and the generated OFDM portion. Moreover, although blocks **926** and **932** are shown later in the flow diagram of example method **920** than blocks **924** and **930**, respectively, blocks **926** and **932** occur before, or simultaneously with, blocks **924** and **930** in other embodiments.

FIG. **16** is a flow diagram of an example method **940** for auto-detecting a clock rate of a data unit generated according to the first example preamble design (of which an example embodiment is shown in FIG. **7**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG.

1 (and/or a client station such as the client station **25-1**) is configured to implement the method **940**.

At block **942**, a data unit is received via a communication channel. Block **942** is similar to block **912** of the method **910** in FIG. **14**, in some embodiments. The data unit received at block **942** includes a first preamble portion, and an OFDM portion that follows the first preamble portion. The OFDM portion of the data unit includes a second preamble portion including one or more LTFs. According to various embodiments, the received data unit is a data unit having the preamble design described in connection with FIG. **7**. Additionally or alternatively, according to various embodiments, the received data unit is a data unit generated according to the method **900** of FIG. **15**.

At block **944**, a first autocorrelation of at least the first preamble portion of the data unit received at block **942** is performed, where the first autocorrelation is performed using a first repetition period and outputs a first carrier sense signal. In an embodiment, the first repetition period is the same as a first potential length of a repeating sequence in the first preamble portion. For example, for the example preamble design shown in FIG. **7**, the first repetition period is equal to 0.8 μs or another suitable duration.

At block **948**, a second autocorrelation of at least the first preamble portion of the data unit received at block **942** is performed, where the second autocorrelation is performed using a second repetition period and outputs a second carrier sense signal. In an embodiment, the second repetition period is the same as a second potential length of a repeating sequence in the first preamble portion, different than the first potential length. For example, for the example preamble design shown in FIG. **7**, the second repetition period is equal to 3.2 μs or another suitable duration. In an embodiment, the first autocorrelation of block **944** is performed at least partially in parallel with the second autocorrelation at block **948**.

At block **950**, it is determined whether both the first autocorrelation and the second autocorrelation indicate the presence of a carrier (e.g., whether the first carrier sense signal and the second carrier sense signal indicate the presence of a carrier, in an embodiment). For example, in an embodiment, it is determined whether both the first carrier sense signal and the second carrier sense signal are at a "high" level (or any other indicator of a relatively strong autocorrelation).

If it is determined at block **950** that both the first autocorrelation and the second autocorrelation indicate the presence of a carrier, flow proceeds to block **952**. At block **952**, the clock rate of the OFDM portion of the data unit received at block **942** is determined based on a pulse length of the first carrier sense signal (i.e., the first autocorrelation output,) and/or a pulse length of the second carrier sense signal (i.e., the second autocorrelation output). In an embodiment, the clock rate of the OFDM portion is determined to be a first clock rate if the first carrier sense signal and/or the second carrier sense signal are at a "high" level (or any other suitable indicator of a relatively strong autocorrelation) for a first length of time (e.g., 0.8 μs), and is determined to be a lower, second clock rate if the first carrier sense signal and/or the second carrier sense signal are at a "high" level (or any other suitable indicator of a relatively strong autocorrelation) for a longer, second length of time (e.g., 3.2 μs). In some embodiments, the determination at block **950** is performed by determining whether a pulse length of the first and/or second carrier sense signal is in a first length range (e.g., less than 10 μs) or a second length range (e.g., greater than 10 μs). In an embodiment, the pulse length of the first and second carrier sense signals corresponds to the length of time between i) sensing a carrier and ii) detecting a transition from the first preamble portion of the received data unit to the second preamble portion of the received data unit.

On the other hand, if it is determined at block **950** that the first autocorrelation output or the second autocorrelation output (but not both) does not indicate the presence of a carrier, flow proceeds to block **954**. At block **954**, the clock rate of the OFDM portion of the data unit received at block **942** is determined based on which autocorrelation indicates the presence of a carrier. For example, in an embodiment, the clock rate of the OFDM portion is determined to be a first clock rate when the first (but not the second) autocorrelation indicates a carrier sense, and is determined to be a lower, second clock rate when the second (but not the first) autocorrelation indicates a carrier sense.

In some embodiments, the method **940** includes additional method elements not shown in FIG. **16**. For example, in an embodiment, the method **940** includes providing, prior to receiving the data unit at block **942**, a receiver clock rate that corresponds to the first, higher potential clock rate of received data units. Moreover, while the method **940** has been described with reference to determining a first and a second clock rate, some embodiments include additional method elements (e.g., similar to blocks **944** and **948**) corresponding to a third clock rate, a third and a fourth clock rate, etc., where it is also determined at block **952** or **954** whether the clock rate of the OFDM portion is one of these additional potential clock rates. In embodiments utilizing a third or more clock rates, block **950** is modified to determine whether more than one autocorrelation output indicates presence of a carrier, and block **952** is modified to consider a third or more autocorrelation outputs.

FIG. **17** is a flow diagram of an example method **960** for generating a data unit according to the second example preamble design (of which an example embodiment is shown in FIG. **8**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **960** to generate a data unit for transmission over a communication channel.

At block **962**, it is determined whether a PHY mode of a communication device implementing the method **960** is a first PHY mode or a second PHY mode. In various embodiments, block **962** is similar to block **922** of method **920** in FIG. **15**.

If it is determined at block **962** that the PHY mode is the first PHY mode, the flow proceeds to block **964**. At block **964**, a first number of repetitions (i.e., one or more repetitions) of a sequence is generated in a first preamble portion. In some embodiments, the first preamble portion is generated using a first clock rate corresponding to the clock rate of an OFDM portion when in the first PHY mode, while in other embodiments the first preamble portion is generated using a second clock rate that corresponds to the clock rate of an OFDM portion when in the second PHY mode. In an embodiment, the repeated sequences of the first preamble portion are OFDM-modulated (e.g., are OFDM-modulated sequences of an STF, in an embodiment).

At block **968**, an OFDM portion is generated using the first clock rate. In various embodiments, block **968** is similar to block **926** of method **920** in FIG. **15**.

If it is determined at block **962** that the PHY mode is the second PHY mode, the flow proceeds to block **970**. At block **970**, a second number of repetitions of a sequence is generated in a first preamble portion. The second number of repetitions is greater than the first number of repetitions generated at block **964**, and causes the first preamble portion to be longer than the first preamble portion generated at block **964**. In an embodiment, each repeating sequence generated at

block **970** is the same as each repeating sequence generated at block **964**. For example, in an embodiment, the sequences of the first preamble portion are generated at block **970** using the same clock rate as is used to generate the sequences of the first preamble portion at block **964**, and the sequences of the first preamble portions generated at blocks **964** and **970** are both OFDM-modulated sequences of an STF.

At block **972**, an OFDM portion is generated using the second clock rate. In various embodiments, block **972** is similar to block **932** of method **920** in FIG. **15**.

In some embodiments, the method **960** of FIG. **17** includes additional method elements not shown. For example, in an embodiment, after block **968** and block **972** an additional method element includes transmitting via a communication channel (e.g., a wireless communication channel) a data unit that includes both the generated first preamble portion and the generated OFDM portion. Moreover, although blocks **968** and **972** are shown later in the flow diagram of example method **960** than blocks **964** and **970**, respectively, blocks **968** and **972** occur before, or simultaneously with, blocks **964** and **970** in other embodiments.

FIG. **18** is a flow diagram of an example method **980** for auto-detecting a clock rate of a data unit generated according to the second example preamble design (of which an example embodiment is shown in FIG. **8**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **980**.

At block **982**, a data unit is received via a communication channel. Block **982** is similar to block **912** of the method **910** in FIG. **14**, in some embodiments. The data unit received at block **982** includes a first preamble portion, and an OFDM portion that follows the first preamble portion. The OFDM portion of the data unit includes a second preamble portion including one or more LTFs. According to various embodiments, the received data unit is a data unit having the preamble design described in connection with FIG. **8**. Additionally or alternatively, according to various embodiments, the received data unit is a data unit generated according to the method **960** of FIG. **17**.

At block **984**, an autocorrelation of at least a first preamble portion of the data unit received at block **982** is performed, where the autocorrelation outputs a carrier sense signal.

At block **988**, the clock rate of the OFDM portion of the data unit received at block **982** is determined based on a pulse length of the carrier sense signal (i.e., the autocorrelation output). In an embodiment, the clock rate of the OFDM portion is determined to be a first clock rate if the carrier sense signal is at a "high" level (or any other indicator of a relatively strong autocorrelation) for a first length of time (e.g., 0.8 μs), and is determined to be a lower, second clock rate if the carrier sense signal is at a "high" level (or any other indicator of a relatively strong autocorrelation) for a longer, second length of time (e.g., 3.2 μs). In some embodiments, the determination at block **988** is performed by determining whether a pulse length of the carrier sense signal is in a first length range (e.g., less than 10 μs) or a second length range (e.g., greater than 10 μs). The pulse length depends on the number of repeated sequences in the first preamble portion of the data unit, in an embodiment. In an embodiment, the pulse length of the carrier sense signal (e.g., duration of a pulse in the carrier sense signal) corresponds to an estimation of a length of time between i) sensing a carrier and ii) detecting a transition from the first preamble portion of the received data unit to the second preamble portion of the received data unit.

In some embodiments, the method **988** includes additional method elements not shown in FIG. **18**. For example, in an embodiment, the method **980** includes providing, prior to receiving the data unit at block **982**, a receiver clock rate that corresponds to the first, higher potential clock rate of received data units. Moreover, while the method **980** has been described with reference to determining a first and a second clock rate, some embodiments include additional method elements (e.g., similar to block **984**) corresponding to a third clock rate, a third and a fourth clock rate, etc., where it is also determined at block **988** whether the clock rate of the OFDM portion is one of these additional potential clock rates.

FIG. **19** is a flow diagram of an example method **1000** for generating a data unit according to the third example preamble design (of which an example embodiment is shown in FIG. **9**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **1000** to generate a data unit for transmission over a communication channel.

At block **1002**, it is determined whether a PHY mode of a communication device implementing the method **1000** is a first PHY mode or a second PHY mode. In various embodiments, block **1002** is similar to block **922** of method **920** in FIG. **15**.

If it is determined at block **1002** that the PHY mode is the first PHY mode, the flow proceeds to block **1004**. At block **1004**, a first number of repetitions (i.e., one or more repetitions) of a sequence (i.e., one or more repetitions) is generated in a first preamble portion. Block **1004** is similar to block **964** in method **960** of FIG. **17**, in an embodiment.

At block **1008**, the first preamble portion generated at block **1004** is augmented using a first cover code. For example, in an embodiment, the first preamble portion is augmented using a sequence of all ones (i.e., such that the polarity of all bits in all repeating sequences of the first preamble portion is not changed). In one embodiment where the first cover code is a sequence of all ones, augmenting the first preamble portion at block **1008** comprises simply not performing any cover code processing operation on the first preamble portion. In an embodiment where the first cover code is a sequence of all ones, block **1008** is omitted.

At block **1010**, an OFDM portion is generated using a first clock rate corresponding to the first PHY mode. In various embodiments, block **968** is similar to block **926** of method **920** in FIG. **15**.

If it is determined at block **1002** that the PHY mode is the second PHY mode, the flow proceeds to block **1012**. At block **1012**, a second number of repetitions (i.e., one or more repetitions) of a sequence is generated in a first preamble portion. In one embodiment, the second number of repetitions is the same as the first number of repetitions generated at block **1004** (i.e., the number of repetitions, and therefore first preamble portion length, does not reflect the PHY mode or the clock rate of the OFDM portion). In another embodiment, the second number of repetitions is greater than the first number of repetitions generated at block **1004**, and results in the first preamble portion being longer than the first preamble portion generated at block **1004**. In an embodiment, each repeating sequence generated at block **1012** is the same as each repeating sequence generated at block **1004**. For example, in an embodiment, the sequences of the first preamble portion are generated at block **1012** using the same clock rate as is used to generate the sequences of the first preamble portion at block **1004**, and the sequences of the first preamble portions generated at blocks **1004** and **1012** are both OFDM-modulated sequences of an STF.

At block **1014**, the first preamble portion generated at block **1012** is augmented using a second cover code that is

different than the first cover code utilized for the first PHY mode. For example, in one embodiment where the first cover code is a sequence of all ones, the first preamble portion is augmented at block **1014** using a series of alternating positive and negative ones (e.g., such that the polarity of all bits in every second instance of the sequence is changed, in an embodiment). In an embodiment where the second cover code is a sequence of all ones, augmenting the first preamble portion at block **1014** comprises simply not performing any cover code processing operation on the first preamble portion. In an embodiment where the second cover code is a sequence of all ones, block **1014** is omitted.

At block **1018**, an OFDM portion is generated using a second clock rate corresponding to the second PHY mode. In various embodiments, block **1018** is similar to block **932** of method **920** in FIG. **15**.

In some embodiments, the method **1000** of FIG. **19** includes additional method elements not shown. For example, in an embodiment, after block **1010** block **1018**, an additional method element includes transmitting via a communication channel (e.g., a wireless communication channel) a data unit that includes both the generated first preamble portion and the generated OFDM portion. Moreover, the sequence of blocks in each path of the method **1000** is different in various embodiments, and/or one or more of the blocks of the method **1000** is performed simultaneously with other blocks. For example, blocks **1004** and **1008** (or blocks **1012** and **1014**) occur after or in parallel with block **1010** (or block **1018**), in an embodiment.

FIG. **20** is a flow diagram of an example method **1020** for auto-detecting a clock rate of a data unit generated according to the third example preamble design (of which an example embodiment is shown in FIG. **9**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **1020**.

At block **1022**, a data unit is received via a communication channel. Block **1022** is similar to block **912** of the method **910** in FIG. **14**, in some embodiments. The data unit received at block **1022** includes a first preamble portion, and an OFDM portion that follows the first preamble portion. The OFDM portion of the data unit includes a second preamble portion including one or more LTFs. According to various embodiments, the received data unit is a data unit having the preamble design described in connection with FIG. **9**. Additionally or alternatively, according to various embodiments, the received data unit is a data unit generated according to the method **1000** of FIG. **19**.

At block **1024**, at least a first preamble portion of the data unit received at block **1022** is processed to remove or undo a first possible cover code. For example, in an embodiment, a first possible cover code is a series of ones, utilized by transmitting devices that transmit data units in a first PHY mode using a first clock rate. In an embodiment where the first possible cover code is a series of ones, block **1024** is omitted.

At block **1028**, a first autocorrelation of at least the first preamble portion (as processed at block **1024**) is performed. The first autocorrelation is performed using a first repetition period and outputs a first carrier sense signal. In an embodiment, block **1028** is similar to block **944** of FIG. **16**.

At block **1030**, at least the first preamble portion of the data unit received at block **1022** is processed to remove or undo a second possible cover code. For example, in one embodiment where the first possible cover code is a series of ones utilized by transmitting devices in a first PHY mode using a first clock rate, a second possible cover code is a series of alternating positive and negative ones utilized by transmitting devices in a second PHY mode using a second clock rate different than the first clock rate. In an embodiment, block **1030** is performed in parallel with block **1024**. In an embodiment where the second possible cover code is a series of ones, block **1030** is omitted.

At block **1032**, a second autocorrelation of at least the first preamble portion (as processed at block **1030**) is performed, where the second autocorrelation is performed using a second repetition period and outputs a second carrier sense signal. In an embodiment, block **1032** is similar to block **948** of FIG. **16** (e.g., in an embodiment, block **1032** is performed in parallel with block **1028**).

At block **1034**, the clock rate of the OFDM portion of the data unit received at block **1022** is determined based on which autocorrelation output indicates the presence of a carrier. For example, in an embodiment, if the first carrier sense signal output by the first autocorrelation performed at block **1028** indicates the presence of a carrier (e.g., outputs a "high" level, or otherwise indicates a relatively strong autocorrelation), it is determined that the clock rate is the first clock rate, and if the second carrier sense signal output by the second autocorrelation performed at block **1032** indicates the presence of a carrier (e.g., outputs a "high" level, or otherwise indicates a relatively strong autocorrelation), it is determined that the clock rate is the second clock rate.

Because each of the first and second autocorrelations follows processing that attempts to remove or undo one of the alternative cover codes of the preamble design scheme, most likely only one of the first and second carrier sense signals will indicate the presence of a carrier. Moreover, this carrier sensing generally occurs near the beginning of a carrier sense signal pulse, without having to wait to see the length of the pulse. Accordingly, in an embodiment, the receiver clock is dynamically adjusted to correspond to the clock rate of the received data unit based on the determination at block **1034**.

In some embodiments, the method **1020** includes additional method elements not shown in FIG. **20**, such as dynamically adjusting the receiver clock as described above, for example. Moreover, while the method **1020** has been described with reference to determining a first and a second clock rate, some embodiments include additional method elements (e.g., similar to blocks **1024** and **1028**) corresponding to a third clock rate, a third and a fourth clock rate, etc., where it is also determined at block **1034** whether the clock rate of the OFDM portion is one of these additional potential clock rates.

FIG. **21** is a flow diagram of an example method **1040** for generating a data unit according to the fourth or fifth example preamble design (of which example embodiments are shown in FIGS. **10** and **11**, respectively), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **1040** to generate a data unit for transmission over a communication channel.

At block **1042**, it is determined whether a PHY mode of a communication device implementing the method **1040** is a first PHY mode or a second PHY mode. In various embodiments, block **1042** is similar to block **922** of method **920** in FIG. **15**.

If it is determined at block **1042** that the PHY mode is the first PHY mode, the flow proceeds to block **1044**. At block **1044**, a first SYNC field is generated in a first preamble portion, where the first preamble portion is an SC "extra preamble" portion as discussed above. In some embodiments, the first SYNC field includes a repeating sequence (e.g., a repeating Barker sequence, Golay code sequence, etc., according to various embodiments). In an embodiment, the

first SYNC field is the same as or substantially similar to a SYNC field conforming to the IEEE 802.11b standard.

At block **1048**, a start frame delimiter (SFD) field is generated. The SFD field is included in the first preamble portion and follows the SYNC field generated at block **1044**. In an embodiment, the SFD field is the same as or substantially similar to an SFD field conforming to the IEEE 802.11b standard. The SFD field is clocked at the same rate as the SYNC field, in an embodiment.

At block **1050**, an OFDM portion is generated using a first clock rate corresponding to the first PHY mode. In various embodiments, block **1050** is similar to block **926** of method **920** in FIG. **15**.

If it is determined at block **1042** that the PHY mode is the second PHY mode, the flow proceeds to block **1052**. At block **1052**, a second SYNC field, different than the first SYNC field generated at block **1044**, is generated in a first preamble portion. In one embodiment, the second SYNC field has a length that is different than the length of the first SYNC field generated at block **1044**. Alternatively, in another embodiment, the second SYNC field includes a repeating sequence that is complementary to a repeating sequence of the first SYNC field. For example, in an embodiment, the first and second SYNC fields include complementary Golay code sequences. In an embodiment, the second SYNC field is the same as or substantially similar to a SYNC field conforming to the IEEE 802.11b standard. Moreover, in an embodiment, the second SYNC field is clocked at the same rate as the first SYNC field.

At block **1054**, an SFD field is generated. The SFD field is included in the first preamble portion and follows the SYNC field generated at block **1052**. In one embodiment, the SFD field generated at block **1054** is the same as the SFD field generated at block **1048**. In another embodiment, the SFD field generated at block **1054** is different than the SFD field generated at block **1048**. For example, in an embodiment where the first and second SYNC fields generated at blocks **1044** and **1052** include complementary Golay code sequences Ga and Gb, respectively, the SFD field generated at block **1048** includes one or more repetitions of Gb and the SFD field generated at block **1054** includes one or more repetitions of Ga. The SFD field is clocked at the same rate as the SYNC field, in an embodiment.

At block **1058**, an OFDM portion is generated using a second clock rate corresponding to the second PHY mode. In various embodiments, block **1058** is similar to block **926** of method **920** in FIG. **15**.

In some embodiments, the method **1040** of FIG. **21** includes additional method elements not shown. For example, in an embodiment, after block **1050** and block **1058** an additional method element includes transmitting via a communication channel (e.g., a wireless communication channel) a data unit that includes both the generated first preamble portion and the generated OFDM portion. Moreover, the sequence of blocks in each path of the method **1040** is different in various embodiments, and/or one or more of the blocks of the method **1040** is performed simultaneously with other blocks For example, blocks **1044** and **1048** (or blocks **1052** and **1054**) occur after or in parallel with block **1050** (or block **1058**), in an embodiment. Further, in some embodiments, blocks **1048** and **1054** are omitted (i.e., the generated first preamble portion, and therefore the generated data unit, does not include an SFD regardless of PHY mode). Still further, in some embodiments where blocks **1048** and **1054** are included (i.e., an SFD is included in the first preamble portion), the OFDM portion generated at block **1050** and at block **1058** does not include an STF, and an LTF of the OFDM portion immediately follows the SFD of the first preamble portion.

FIG. **22** is a flow diagram of an example method **1060** for auto-detecting a clock rate of a data unit generated according to the fourth or fifth example preamble design (of which example embodiments are shown in FIGS. **10** and **11**, respectively), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **1060**.

At block **1062**, a data unit is received via a communication channel. Block **1062** is similar to block **912** of the method **910** in FIG. **14**, in some embodiments. The data unit received at block **1062** includes a first preamble portion that is an SC "extra preamble" including a SYNC field and, in some embodiments, an SFD following the SYNC field. An OFDM portion of the data unit follows the first preamble portion. The OFDM portion of the data unit includes a second preamble portion including one or more LTFs and, in some embodiments, an STF preceding the LTF(s). According to various embodiments, the received data unit is a data unit having the preamble design described in connection with FIG. **10** or a data unit having the preamble design described in connection with FIG. **11**. Additionally or alternatively, according to various embodiments, the received data unit is a data unit generated according to the method **1040** of FIG. **21**.

At block **1064**, a clock rate of the OFDM portion of the data unit received at block **1062** is auto-detected or determined based on the SYNC field in the first preamble portion of the data unit. More specifically, it is determined whether the clock rate is a first clock rate corresponding to a first PHY mode or a lower, second clock rate corresponding to a second PHY mode, in an embodiment. In various embodiments, the PHY modes are similar to any of the PHY modes described in connection with block **902** of method **900** in FIG. **13**.

In some embodiments, the clock rate of the OFDM portion is determined based on a length of the SYNC field (e.g., when received data units conform to the fourth example preamble design of FIG. **10**). In other embodiments, the clock rate of the OFDM portion is determined based on the repeating sequence of the SYNC field (e.g., when received data units conform to the fourth example preamble design of FIG. **11**). For example, in an embodiment, the clock rate is determined based on whether a first Golay code sequence is included in the SYNC field or a second, complementary Golay code sequence is included in the SYNC field. In one embodiment, where received data units also utilize different SFDs to indicate the clock rate, determining the clock rate at block **1064** includes determining the clock rate also based on the SFD of the first preamble portion of the received data unit.

Although FIG. **22** shows only blocks **1062** and **1064** in the method **1060**, some embodiments include additional method elements. Moreover, while the method **1060** has been described with reference to determining a first or a second clock rate, some embodiments additionally determine (at block **1064**) whether the clock rate is a third clock rate, whether the clock rate is a third or fourth clock rate, etc.

FIG. **23** is a flow diagram of an example method **1080** for generating a data unit according to the sixth example preamble design (of which an example embodiment is shown in FIG. **12**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **1080** to generate a data unit for transmission over a communication channel.

At block **1082**, it is determined whether a PHY mode of a communication device implementing the method **1080** is a first PHY mode or a second PHY mode. In various embodiments, block **1082** is similar to block **922** of method **920** in FIG. **15**.

If it is determined at block **1082** that the PHY mode is the first PHY mode, the flow proceeds to block **1084**. At block **1084**, a SYNC field is generated in a first preamble portion, where the first preamble portion is an SC "extra preamble" portion as discussed above. In some embodiments, the SYNC field includes a repeating sequence (e.g., a repeating Barker sequence, Golay code sequence, etc., according to various embodiments). In an embodiment, the SYNC field is the same as or substantially similar to a SYNC field conforming to the IEEE 802.11b standard.

At block **1088**, a first SFD field is generated. The first SFD field is included in the first preamble portion and follows the SYNC field generated at block **1084**. In an embodiment, the first SFD field is the same as or substantially similar to an SFD field conforming to the IEEE 802.11b standard. The SFD field is clocked at the same rate as the SYNC field, in an embodiment.

At block **1090**, an OFDM portion is generated using a first clock rate corresponding to the first PHY mode. In various embodiments, block **1090** is similar to block **926** of method **920** in FIG. **15**.

If it is determined at block **1082** that the PHY mode is the second PHY mode, the flow proceeds to block **1092**. At block **1092**, a SYNC field is generated in a first preamble portion. The SYNC field is the same as or substantially the same as the SYNC field generated at block **1084**, in an embodiment.

At block **1094**, a second SFD field different than the first SFD field is generated. For example, in one embodiment, the second SFD field includes a sequence that is repeated in the SYNC field but with a sign flip, while the first SFD field includes the same sequence of the SYNC field without the sign flip. As another example, in an embodiment, the second SFD field includes one or more repetitions of a sequence that is different than a sequence repeated one or more times in the first SFD field. The second SFD field is included in the first preamble portion and follows the SYNC field generated at block **1092**. The second SFD field is clocked at the same rate as the SYNC field, in an embodiment.

At block **1098**, an OFDM portion is generated using a second clock rate corresponding to the second PHY mode. In various embodiments, block **1098** is similar to block **926** of method **920** in FIG. **15**.

In some embodiments, the method **1080** of FIG. **23** includes additional method elements not shown. For example, in an embodiment, after block **1090** and block **1098** an additional method element includes transmitting via a communication channel (e.g., a wireless communication channel) a data unit that includes both the generated first preamble portion and the generated OFDM portion. Moreover, the sequence of blocks in each path of the method **1080** is different in various embodiments, and/or one or more of the blocks of the method **1080** is performed simultaneously with other blocks. For example, blocks **1084** and **1088** (or blocks **1092** and **1094**) occur after or simultaneously with block **1090** (or block **1098**), in an embodiment. In some embodiments, the OFDM portion generated at block **1090** and at block **1098** does not include an STF, and an LTF of the OFDM portion immediately follows the SFD.

FIG. **24** is a flow diagram of an example method **1100** for auto-detecting a clock rate of a data unit generated according to the sixth example preamble design (of which an example embodiment is shown in FIG. **12**), according to an embodiment. In some embodiments, an AP such as the AP **14** of FIG. **1** (and/or a client station such as the client station **25-1**) is configured to implement the method **1100**.

At block **1102**, a data unit is received via a communication channel. Block **1102** is similar to block **912** of the method **910** in FIG. **14**, in some embodiments. The data unit received at block **1102** includes a first preamble portion that is an SC "extra preamble" including a SYNC field and an SFD following the SYNC field. An OFDM portion of the data unit follows the first preamble portion. The OFDM portion of the data unit includes a second preamble portion including one or more LTFs and, in some embodiments, an STF preceding the LTF(s). In some embodiments, however, the second preamble portion does not include an STF, and the LTF(s) immediately follow the SFD of the first preamble portion. According to various embodiments, the received data unit is a data unit having the preamble design described in connection with FIG. **12**. Additionally or alternatively, according to various embodiments, the received data unit is a data unit generated according to the method **1080** of FIG. **23**.

At block **1104**, a clock rate of the OFDM portion of the data unit received at block **1102** is auto-detected or determined based on the SFD field (but not based on the SYNC field) in the first preamble portion of the data unit. More specifically, it is determined whether the clock rate is a first clock rate corresponding to a first PHY mode or a lower, second clock rate corresponding to a second PHY mode, in an embodiment. In various embodiments, the PHY modes are similar to any of the PHY modes described in connection with block **902** of method **900** in FIG. **13**.

In some embodiments, the SFD field (and, therefore, the clock rate of the OFDM portion) is determined by performing parallel cross-correlations. For example, in an embodiment, a first cross-correlation correlates a received SFD sequence with a first potential SFD sequence corresponding to the first clock rate, and a second cross-correlation correlates the received SFD sequence with a second potential SFD sequence corresponding to the second clock rate.

Although FIG. **24** shows only blocks **1102** and **1104** in the method **1100**, some embodiments include additional method elements. Moreover, while the method **1100** has been described with reference to determining a first and a second clock rate, some embodiments additionally determine (at block **1104**) whether the clock rate is a third clock rate, whether the clock rate is a third or fourth clock rate, etc.

At least some of the various blocks, operations, and techniques described above may be implemented utilizing hardware, a processor executing firmware instructions, a processor executing software instructions, or any combination thereof. When implemented utilizing a processor executing software or firmware instructions, the software or firmware instructions may be stored in any computer readable memory such as on a magnetic disk, an optical disk, or other storage medium, in a RAM or ROM or flash memory, processor, hard disk drive, optical disk drive, tape drive, etc. Likewise, the software or firmware instructions may be delivered to a user or a system via any known or desired delivery method including, for example, on a computer readable disk or other transportable computer storage mechanism or via communication media. Communication media typically embodies computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or

direct-wired connection, and wireless media such as acoustic, radio frequency, infrared and other wireless media. Thus, the software or firmware instructions may be delivered to a user or a system via a communication channel such as a telephone line, a DSL line, a cable television line, a fiber optics line, a wireless communication channel, the Internet, etc. (which are viewed as being the same as or interchangeable with providing such software via a transportable storage medium). The software or firmware instructions may include machine readable instructions that, when executed by the processor, cause the processor to perform various acts.

When implemented in hardware, the hardware may comprise one or more of discrete components, an integrated circuit, an application-specific integrated circuit (ASIC), etc.

While the present invention has been described with reference to specific examples, which are intended to be illustrative only and not to be limiting of the invention, changes, additions and/or deletions may be made to the disclosed embodiments without departing from the scope of the invention.

What is claimed is:

1. A method for detecting, at a first communication device, a clock rate of a physical layer (PHY) data unit, the method comprising:

receiving, at the first communication device, the PHY data unit from a second communication device via a communication channel, wherein the PHY data unit includes (i) a first portion and (ii) a second portion following the first portion;

processing, at the first communication device, the first portion of the PHY data unit, wherein processing the first portion of the PHY data unit includes performing one or more autocorrelations to generate one or more respective autocorrelation outputs; and

determining, at the first communication device and based on at least one of the one or more autocorrelation outputs, a clock rate of the second portion of the PHY data unit.

2. The method of claim **1**, wherein:

the first portion of the PHY data unit includes a number of repetitions of a sequence; and

performing one or more autocorrelations includes (i) performing a first autocorrelation of at least the first portion of the PHY data unit, using a first repetition period, to generate a first autocorrelation output, and (ii) performing a second autocorrelation of at least the first portion of the PHY data unit, using a second repetition period longer than the first repetition period, to generate a second autocorrelation output.

3. The method of claim **2**, wherein determining a clock rate of the second portion of the PHY data unit includes:

when both the first autocorrelation output and the second autocorrelation output indicate a presence of a carrier, determining the clock rate of the second portion of the PHY data unit based on at least one of (i) a pulse length of the first autocorrelation output and (ii) a pulse length of the second autocorrelation output.

4. The method of claim **1**, wherein:

the first portion of the PHY data unit includes a number of repetitions of a sequence;

performing one or more autocorrelations includes performing an autocorrelation of at least the first portion of the PHY data unit to generate an autocorrelation output; and

determining a clock rate of the second portion of the PHY data unit includes determining the clock rate of the second portion of the PHY data unit based on at least a pulse length of the autocorrelation output, wherein the pulse length of the autocorrelation output depends on the number of repetitions of the sequence.

5. The method of claim **1**, wherein processing the first portion of the PHY data unit further includes, prior to performing the one or more autocorrelations, at least one of (i) processing the first portion of the PHY data unit to remove a first possible cover code from the first portion of the PHY data unit and (ii) processing the second portion of the PHY data unit to remove a second possible cover code from the first portion of the PHY data unit.

6. The method of claim **5**, further comprising:

dynamically adjusting a receiver clock of the first communication device based on a determination of the clock rate of the second portion of the PHY data unit.

7. The method of claim **1**, wherein:

the first portion of the PHY data unit is a first preamble portion;

the second portion of the PHY data unit is an orthogonal frequency division multiplexing (OFDM) portion following the first preamble portion; and

the OFDM portion includes a second preamble portion including one or more long training fields.

8. A communication device comprising:

a network interface device configured to

receive a physical layer (PHY) data unit via a communication channel, wherein the PHY data unit includes (i) a first portion and (ii) a second portion following the first portion,

process the first portion of the PHY data unit at least in part by performing one or more autocorrelations to generate one or more respective autocorrelation outputs, and

determine, based on at least one of the one or more autocorrelation outputs, a clock rate of the second portion of the PHY data unit.

9. The communication device of claim **8**, wherein:

the first portion of the PHY data unit includes a number of repetitions of a sequence; and

the network interface device is configured to perform one or more autocorrelations at least by (i) performing a first autocorrelation of at least the first portion of the PHY data unit, using a first repetition period, to generate a first autocorrelation output, and (ii) performing a second autocorrelation of at least the first portion of the PHY data unit, using a second repetition period longer than the first repetition period, to generate a second autocorrelation output.

10. The communication device of claim **9**, wherein the network interface device is configured to determine the clock rate of the second portion of the PHY data unit at least by:

when both the first autocorrelation output and the second autocorrelation output indicate a presence of a carrier, determining the clock rate of the second portion of the PHY data unit based on at least one of (i) a pulse length of the first autocorrelation output and (ii) a pulse length of the second autocorrelation output.

11. The communication device of claim **8**, wherein:

the first portion of the PHY data unit includes a number of repetitions of a sequence;

the network interface device is configured to perform one or more autocorrelations at least by performing an autocorrelation of at least the first portion of the PHY data unit to generate an autocorrelation output; and

the network interface device is configured to determine the clock rate of the second portion of the PHY data unit based on at least a pulse length of the autocorrelation

output, wherein the pulse length of the autocorrelation output depends on the number of repetitions of the sequence.

12. The communication device of claim **8**, wherein the network interface device is configured to process the first portion of the PHY data unit further by, prior to performing the one or more autocorrelations, at least one of (i) processing the first portion of the PHY data unit to remove a first possible cover code from the first portion of the PHY data unit and (ii) processing the second portion of the PHY data unit to remove a second possible cover code from the first portion of the PHY data unit.

13. The communication device of claim **12**, wherein the network interface device is further configured to:

dynamically adjust a receiver clock of the communication device based on a determination of the clock rate of the second portion of the PHY data unit.

14. The communication device of claim **1**, wherein:

the first portion of the PHY data unit is a first preamble portion;

the second portion of the PHY data unit is an orthogonal frequency division multiplexing (OFDM) portion following the first preamble portion; and

the OFDM portion includes a second preamble portion including one or more long training fields.

15. A tangible, non-transitory computer-readable medium storing instructions that, when executed by one or more processors of a communication device, cause the one or more processors to:

process a physical layer (PHY) data unit received via a communication channel, wherein

the PHY data unit includes (i) a first portion and (ii) a second portion following the first portion, and

the instructions cause the one or more processors to process the PHY data unit at least by performing one or more autocorrelations to generate one or more respective autocorrelation outputs; and

determine, based on at least one of the one or more autocorrelation outputs, a clock rate of the second portion of the PHY data unit.

16. The tangible, non-transitory computer-readable medium of claim **15**, wherein:

the first portion of the PHY data unit includes a number of repetitions of a sequence; and

the instructions cause the one or more processors to perform one or more autocorrelations at least by (i) performing a first autocorrelation of at least the first portion of the PHY data unit, using a first repetition period, to generate a first autocorrelation output, and (ii) performing a second autocorrelation of at least the first portion of the PHY data unit, using a second repetition period longer than the first repetition period, to generate a second autocorrelation output.

17. The tangible, non-transitory computer-readable medium of claim **16**, wherein the instructions cause the one or more processors to determine the clock rate of the second portion of the PHY data unit at least by:

when both the first autocorrelation output and the second autocorrelation output indicate a presence of a carrier, determining the clock rate of the second portion of the PHY data unit based on at least one of (i) a pulse length of the first autocorrelation output and (ii) a pulse length of the second autocorrelation output.

18. The tangible, non-transitory computer-readable medium of claim **15**, wherein:

the first portion of the PHY data unit includes a number of repetitions of a sequence;

the instructions cause the one or more processors to perform one or more autocorrelations at least by performing an autocorrelation of at least the first portion of the PHY data unit to generate an autocorrelation output; and

the instructions cause the one or more processors to determine the clock rate of the second portion of the PHY data unit based on at least a pulse length of the autocorrelation output, wherein the pulse length of the autocorrelation output depends on the number of repetitions of the sequence.

19. The tangible, non-transitory computer-readable medium of claim **15**, wherein the instructions cause the one or more processors to process the first portion of the PHY data unit further by, prior to performing the one or more autocorrelations, at least one of (i) processing the first portion of the PHY data unit to remove a first possible cover code from the first portion of the PHY data unit and (ii) processing the second portion of the PHY data unit to remove a second possible cover code from the first portion of the PHY data unit.

20. The tangible, non-transitory computer-readable medium of claim **19**, wherein the instructions further cause the one or more processors to:

dynamically adjust a receiver clock of the communication device based on a determination of the clock rate of the second portion of the PHY data unit.

21. The tangible, non-transitory computer-readable medium of claim **15**, wherein:

the first portion of the PHY data unit is a first preamble portion;

the second portion of the PHY data unit is an orthogonal frequency division multiplexing (OFDM) portion following the first preamble portion; and

the OFDM portion includes a second preamble portion including one or more long training fields.

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